Our Children's Trust Youth v. Gov

September 27, 2021

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U.S. Environmental Protection Agency
EPA Docket Center
Washington, DC

Re: Comment for Environmental Protection Agency's Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards - Proposed Rule (Docket No. EPA–HQ–OAR–2021–0208)

Administrator Michael Regan,

On behalf of America's youth, Our Children's Trust provides these comments for the Environmental Protection Agency's ("EPA") "Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards" proposed rule (EPA–HQ–OAR–2021–0208), pursuant to Executive Order 13990. As the Nation's only law firm dedicated to representing youth whose constitutional rights are being infringed by their government's conduct that causes climate change, we write to advise EPA to strengthen the federal greenhouse gas ("GHG") emission standards for passenger cars and light trucks for Model Years ("MY") 2023-2026 beyond the proposed alternative and Alternative 2 so that they meet the urgency of the crisis and align with the kind of deep emission reductions scientists say are needed to protect the climate system and the constitutional rights of youth. We also ask that the EPA revise its Regulatory Impacts Analysis ("RIA")[1] so that it reflects the true costs of climate change, the true benefits of more swiftly electrifying the transportation sector and utilizes no discount rate or a discount rate that does not discriminate against children and future generations.

The federal government has long known that burning fossil fuels causes dangerous climate change that imperils the health and wellbeing of American children. The environmental consequences of vehicle emissions are well documented and are contributing to the catastrophic heat, drought, and wildfires terrorizing the West coast and hurricanes, flooding and tornadoes horrifying the East coast. The costs of these climate change-induced disasters are staggering and many of the victims will be unable to recover. A new study just out shows that children will experience many more of these extreme, life-threatening adults than their elders living today, including the ones making these policy decisions.[2] We are well beyond the time for incremental measures. These rules need to go further, faster and across a longer time horizon so that the entire transportation sector, and supporting industrial sectors, can plan and respond as quickly as feasible. The technology is there to expedite the transition away from the internal combustion engine and eliminate their sales by 2030 for passenger cars and light duty trucks and 2035 for heavy duty vehicles. This is not only economically feasible, it is enormously beneficial. According to your

[1] U. S. EPA, *Revised 2023 and Later Model Year Light- Duty Vehicle GHG Emissions Standards: Regulatory Impact Analysis* (Aug. 2021) [hereinafter *RIA*].
[2] Wim Thiery et al., *Intergenerational Inequities in Exposure to Climate Extremes*, Science (2021).

own RIA:

> [T]here has been a proliferation of recent announcements from automakers signaling a rapidly growing shift in investment away from internal-combustion technologies and toward high levels of electrification. EPA has also heard from a wide range of stakeholders over the past several months, including but not limited to the automotive manufacturers and the automotive suppliers, that the significant investments being made now to develop and launch new EV product offerings and in the expansion of EV charging infrastructure could enable higher levels of EV penetration to occur in the market place by the MY 2026 time frame than we have projected in this proposal for both the proposed MY2026 standards and the Alternative 2 MY2026 standards. RIA at xx.

The RIA demonstrates that Alternative 2's more stringent standards would result in greater net benefits and fuel savings for American drivers than the preferred alternative.[3] The actual benefits of the necessary science-based standards would outpace those analyzed in the RIA. There is every reason to move more quickly and propose a more stringent alternative than those considered: 1) the U.S. Constitution and your statutory public trust mandate require it; 2) it is technically feasible to decarbonize and electrify transportation more quickly; 3) the auto industry has signaled it can move more quickly than even your most stringent proposal, Alternative 2; and 4) the economic analysis of present value net benefits would be even more favorable for the nation and for consumers if you eliminated the unreasonable and unlawful discount rates from your CBA to more accurately reflect the clear benefit of requiring more stringent GHG emissions and EV standards for passenger cars and light duty trucks, and beyond.

Strengthening the GHG emission standards for passenger cars and light trucks is needed in order to protect the fundamental constitutional rights of children and future generations, particularly children within environmental justice communities, including communities of color, low-income communities, and indigenous communities. Executive Order 13990's policy directive clearly states "to listen to the science; to improve public health and protect our environment; to ensure access to clean air and water; . . . to reduce greenhouse gas emissions[.]" The science is clear. The world must stop fossil fuel emissions as soon as possible, every ton matters and causes more danger[4], and the transportation sector must be an early target for decarbonization. A key tool for EPA to facilitate emission reductions is through strong GHG emission standards for passenger cars and light trucks.

EPA, OMB, and other agencies of the federal government have systematically undermined the rights of young people by conducting cost benefit analyses that strongly favor present generations of adults at the expense of future generations and children. Through the RIA's use of discount rates, EPA is undervaluing the costs of its policies to be borne by children living today

[3] Alternative 2 total net benefits discounted would be $110-180 billion, with fuel savings for consumers totaling $150-290 through 2050, also discounted. In contrast, Alternative 1 total net benefits are only $76-130 billion, with fuel savings of $98-200 billion, illustrating that EPA is selecting an alternative that is less stringent, will allow more GHG emissions from the transportation sector, and will have less economic benefits to society and consumers. RIA at xxii, xxiv.

[4] IPCC, *Summary for Policymakers, in* Climate Change 2021: The Physical Science Basis, SPM-37 (In Press) ("Every tonne of CO_2 emissions adds to global warming.").

and millions of American children of tomorrow. That analysis of costs and benefits affects this proposal on GHG emissions standards and how quickly EPA requires electrification of new vehicles on the roads. In addition to perpetuating the infringement of fundamental rights of youth, EPA violates its mandate to prepare an economic assessment that "shall be as extensive as practicable" by accurately accounting for intergenerational equity.[5] As Frank Ramsey wrote a century ago, discounting the wellbeing of future generations is not defensible. The higher the discount rate used, the more that the rights and interests of young people and future generations are devalued in those calculations. The draft RIA currently uses discount rates of 2.5%, 3%, and 5% in evaluating Social Cost of Greenhouse Gases ("SC-GHG") and 3% and 7% in evaluating other costs and benefits. In the context of evaluating costs and benefits of actions around the climate crisis and intergenerational rights, these discount rates are far too high, leading to SC-GHG estimates that are artificially low. Even the EPA acknowledges that these rates are insufficient with respect to the rights of future generations: "a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts."[6]

As a result, the draft RIA's economic analysis unjustifiably undervalues the benefits of climate action and the costs of GHG emissions for children living today and coming generations, thereby treating them under law unequally. Given the devastating climate change impacts on human output, welfare, and life that are being documented today with present levels of global heating and that are expected to worsen in coming years and decades, the science supports the application of zero or much lower discount rates for long-term policy analysis. <u>Many economists agree that intergenerational equity considerations as well as the likely decreases in standards of living and global productivity due to the high risk of harms from climate change necessitate a discount rate of 0% or even negative discount rates</u>.

In light of these considerations, Our Children's Trust respectfully requests that the EPA revise its RIA with a sensitivity analysis that fully accounts for the rights of children and future generations and then revise its proposed rule in light of that analysis in order to comply with the government's duty to prevent infringement of the constitutional rights of young people and future generations to life, liberty, and property and, importantly, equal protection under law, including the Clean Air Act. The EPA must make the following changes:

1. Strengthen the GHG emission standards so that they are as stringent as possible and in line with the deep GHG emission reductions called for by science and eliminate the credits and offsets that allow some auto manufacturers to avoid transitioning away from the internal combustion engine. EPA should achieve zero emissions from all new passenger vehicles and light-duty trucks by 2030 and for heavy-duty trucks by 2035.
2. Remove from the draft RIA all SC-GHG estimations derived from the use of constitutionally, ethically, and economically indefensible 2.5%, 3% and 5% discount rates as well as the 3% and 7% analyses to the extent those to perpetuate discrimination against children and future generations and overestimate the economic wealth of future generations.
3. Incorporate into the RIA estimations derived using a discount rate methodology that

[5] 42 U.S.C. § 7617(d).

[6] *RIA* at xvii.

properly accounts for intergenerational equity (i.e., either a sensitivity analysis using negative, 0%, and near-zero discount rates or a declining discount rate schedule starting from a discount rate no higher than 1.5%).

4. Incorporate into the draft RIA an assessment of the totality of health and environmental impacts associated with GHG pollutants, and non-GHG pollutants, as these impacts are well-documented and relevant to the burdens imposed by the Rule on youth and future generations. The health costs of all GHG emissions should be fully evaluated in the RIA.

The remainder of this comment provides the justification for these proposed changes based on the best available economic and scientific academic literature. The attachments submitted with this comment provide further details.

EPA Must "Listen to the Science"

As part of its review of national emissions standards for passenger cars and light trucks under section 202(a) of the Clean Air Act, EPA should recognize the scientifically-defensible, economically viable, and technically feasible target of reducing total U.S. emissions by close to 100% by 2050, while simultaneously enhancing sequestration capacity of sinks to drawdown historical cumulative CO_2 emissions, placing the U.S. on an emissions trajectory consistent with returning atmospheric CO_2 to below 350 ppm by 2100.[7] Experts have opined that it is economically and technically feasible to achieve this science-based greenhouse gas emission reduction target and we urge you to heed their advice.[8]

Experts are also clear on three key points relevant to EPA's task at hand.

1. Children are uniquely vulnerable to human-caused climate change because of their developing bodies, higher exposure to air, food, and water per unit body weight, unique behavior patterns, dependence on caregivers, and longevity on the planet.[9] Climate change is causing a public health emergency that is adversely impacting the physical and mental health of American children through, among other impacts, extreme weather events, rising temperatures and increased heat exposure, decreased air quality, altered infectious disease patterns, and food and water insecurity.[10] The RIA confirms some of these disproportionate harms to children.

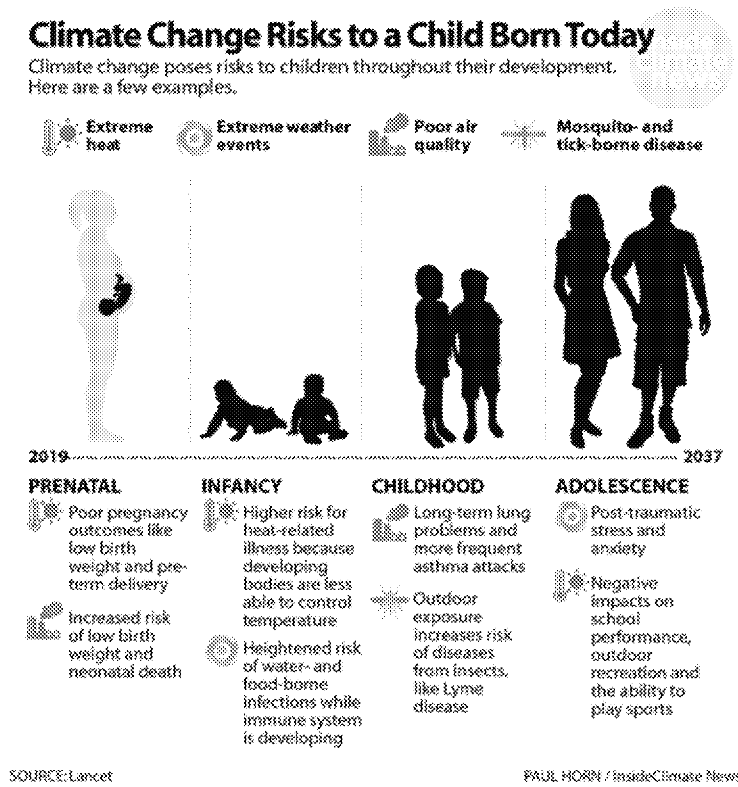
[7] *See* Our Children's Trust, Government Climate and Energy Policies Must Target <350 ppm Atmospheric CO_2 by 2100 to Protect Children and Future Generations (Mar. 2021) [Attachment 1]; James Hansen et al., *Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, 8 PLOS ONE e81648 (2013) [hereinafter *Assessing "Dangerous Climate Change"*]; Expert Report of James E. Hansen, Ph.D., *Juliana v. United States*, No. 6:15-cv-01517 (D. Or. June 28, 2018); Expert Report of Mark Jacobson, Ph.D., *Juliana v. United States*, No. 6:15-cv-01517 (D. Or. June 28, 2018).

[8] *See* Mark Z. Jacobson et al., *100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for the 50 United States*, 8 Energy & Env't Sci. 2093 (2015); Ben Haley et al., *350 ppm Pathways for the United States* (2019) [Attachment 2]; James H. Williams et al., *Carbon-Neutral Pathways for the United States*, 2 AGU Advances e2020AV000284 (2021); Ben Haley et al., *350 ppm Pathways for Florida* (2020) [Attachment 3]; Mark Z. Jacobson, *Zero Air Pollution and Zero Carbon From All Energy Without Blackouts at Low Cost in the Whole United States* (2021) [Attachment 4].

[9] Samantha Ahdoot, Susan E. Pacheco & Council on Environmental Health, *Global Climate Change and Children's Health*, 136 Pediatrics e1468 (2015); Rebecca Pass Philipsborn & Kevin Chan, *Climate Change and Global Child Health*, 141 Pediatrics e20173774 (2018).

[10] *Id.*

RIA at 7-5 to 7-15.



2. "Climate change is a response to energy imbalances in the climate system. For example, rising greenhouse gases directly cause an initial imbalance, the radiative forcing, in the planetary radiation budget, and surface temperatures increase in response as the climate attempts to restore balance."[11] Because of a buildup of CO_2 in Earth's atmosphere (due to human activities, primarily the burning of fossil fuels and deforestation), more solar energy is retained in the atmosphere and less energy is released back into space. CO_2 is the primary driver (or forcer) of climate change. This excess accumulation of GHGs in our atmosphere results in an Earth energy imbalance ("EEI") and thus an accumulation of heat in our climate system.[12] Because of continuing GHG emissions, EEI is increasing and amounts to 0.87 ± 0.12 watts per square meter (W/m^2) during 2010–2018.[13] This energy increase is equivalent to the calories consumed if *each* person in the United States ate 1.7 billion Twinkies—enough to fill 110 Olympic swimming pools. Between 2005–2019, the EEI doubled, representing an unprecedented and rapid warming of our planet.[14] Restoring Earth's energy balance is key to solving the climate crisis and

[11] Ryan J. Kramer et al., *Observational Evidence of Increasing Global Radiative Forcing*, 48 Geophysical Rsch. Letters e2020GL091585 (2021), https://doi.org/10.1029/2020GL091585.
[12] Karina von Schuckmann et al., *Heat Stored in the Earth System: Where Does the Energy Go?*, 12 Earth Syst. Sci. Data, 2013, 2014–15 (2020).
[13] *Id.*
[14] Norman G. Loeb et al., *Satellite and Ocean Data Reveal Marked Increase in Earth's Heating Rate*, 48 Geophysical Rsch. Letters e2021GL093047 (2021), https://doi.org/10.1029/2021GL093047.

scientists say that to do this, we must swiftly reduce GHG emissions by eliminating fossil fuel combustion and protecting and enhancing carbon sinks to sequester more carbon. Earth's energy balance can only be restored by returning the atmospheric CO_2 concentration to below 350 ppm by 2100.[15] Scientists have concluded that "warming will continue even if atmospheric greenhouse gas (GHG) amounts are stabilized at today's level, and the EEI defines additional global warming that will occur without further change in forcing."[16] As such, the target of <350 ppm by 2100 is the best scientific standard for "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. . . . within a time-frame" sufficient to protect life and liberties.[17]

3. Current increased average temperatures of 1°C and greater (now 1.2°C) are already dangerous. Basing decisions that align with temperature targets of 1.5°C is exponentially more catastrophic for our children and posterity. The IPCC special report on *Global Warming of 1.5°C* (2018) stated that allowing a temperature rise of 1.5°C "is not considered 'safe' for most nations, communities, ecosystems and sectors and poses significant risks to natural and human systems as compared to the current warming of 1°C (*high confidence*)."[18] Medical experts have recently recognized that "[t]he science is unequivocal; a global increase of 1.5°C above the pre-industrial average and the continued loss of biodiversity risk *catastrophic harm* to health that will be impossible to reverse."[19] As such, 1.5°C should not be used to guide U.S. transportation policy that is required to be based on best available science.

EPA Must Cease Infringing the Constitutional Rights of Youth

Our Children's Trust represents twenty-one youth plaintiffs, including eleven Black, Brown, and Indigenous youth, in the constitutional climate lawsuit, *Juliana v. United States*. This case asserts that, through the government's affirmative actions that cause climate change, it has violated the youngest generation's constitutional rights to life, liberty, property, and equal protection of the law, as well as failed to protect essential public trust resources. In this litigation, federal courts have affirmed "that the federal government has long promoted fossil fuel use despite knowing that it can cause catastrophic climate change"[20] and "has long understood the risks of fossil fuel use and increasing carbon dioxide emissions. As early as 1965, the Johnson Administration cautioned that fossil fuel emissions threatened significant changes to climate, global temperatures, sea levels, and other stratospheric properties."[21]

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[15] *Assessing "Dangerous Climate Change", supra* note; von Schuckmann et al., *supra* note.
[16] von Schuckmann et al., *supra* note.
[17] UNFCCC, Art. 2.
[18] M.R. Allen et al., *Technical Summary, in* Global Warming of 1.5°C, at 44 (2018); *see also Assessing "Dangerous Climate Change", supra* note.
[19] Lukoye Atwoli et al., *Call for Emergency Action to Limit Global Temperature Increases, Restore Biodiversity, and Protect Health*, The Lancet (2021) (emphasis added), https://doi.org/10.1016/S0140-6736(21)01915-2.
[20] *Juliana v. United States*, 947 F.3d 1159, 1164 (9th Cir. 2020).
[21] *Juliana v. United States*, 947 F.3d 1159, 1166 (9th Cir. 2020).

The Ninth Circuit Court of Appeals found that there was evidence showing that the federal government was a substantial factor in causing the youths' constitutional injuries because "[a] significant portion of [GHG] emissions occur in this country; the United States accounted for over 25% of worldwide emissions from 1850 to 2012, and currently accounts for about 15%."[22] As the EPA has acknowledged, "[t]ransportation is the single largest source of GHG emissions in the United States, making up 29 percent of all emissions," with "[p]assenger cars and trucks contribut[ing] 58 percent of all transportation sources and 17 percent of total U.S. GHG emissions."[23]

Federal courts have also confirmed that the government's conduct in contributing to climate change is causing constitutional injuries to American youth:

> Jaime B., for example, claims that she was forced to leave her home because of water scarcity, separating her from relatives on the Navajo Reservation. . . . Levi D. had to evacuate his coastal home multiple times because of flooding. . . . These injuries are not simply "'conjectural' or 'hypothetical;'" at least some of the plaintiffs have presented evidence that climate change is affecting them now in concrete ways and will continue to do so unless checked.[24]

EPA's control over GHG emissions from the transportation sector must be exercised in a manner that avoids further constitutional infringement by not setting standards that exacerbate American youth's existing climate change injuries.

EPA has Public Trust and Constitutional Obligations to use its Authority to Protect the Atmosphere.

Under the 5th Amendment to the U.S. Constitution, the government is restrained from engaging in conduct that infringes upon fundamental rights to life, liberty, and property, which includes a climate system that sustains human life and liberty. Under the Public Trust Doctrine, embedded in our Constitution and other founding documents, and in the very sovereignty of our Nation, U.S. residents (both present and future, i.e. Posterity) have a right to access and use crucial natural resources, like air and water. The U.S. government, and its executive agencies, have fiduciary duties as trustees to manage, protect, and prevent substantial impairment to our country's vital natural resources which the government holds in trust for present and future generations.[25] As an executive agency of the U.S. government, EPA has an obligation to refrain from activities that substantially impair the atmosphere and other public trust resources (including land, water, and wildlife) and that harm young people's constitutional rights to life, liberty, property, and equal protection of the law.

As part of its proposed rule, EPA must define and recognize the nature of its public trust obligation to ensure it is implementing its statutory authority to set GHG emission standards for passenger vehicles and light trucks in a way that does not substantially impair essential trust

[22] *Juliana v. United States*, 947 F.3d 1159, 1169 (9th Cir. 2020).
[23] U.S. EPA, *Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards: Proposed Rule:: By the Numbers*, EPA (Aug. 2021).
[24] *Juliana v. United States*, 947 F.3d 1159, 1168 (9th Cir. 2020).
[25] *Juliana v. United States*, 217 F. Supp. 3d 1224, 1254 (D. Or. 2016).

resources or limit the ability of youth and future generations from accessing and enjoying trust resources in the short- and long-term. As the honorable Judge Ann Aiken stated in her decision to deny the government's motion to dismiss *Juliana*, "the right to a climate system capable of sustaining human life is fundamental to a free and ordered society,"[26] and EPA should align its policies to ensure this right is not violated.

EPA's Actions Must Be Aligned with Restoring Earth's Energy Imbalance.

The Earth's energy imbalance is already in the danger zone according to scientists, including those within the federal government.[27] Scientists state the "Earth energy imbalance (EEI) is the most critical number defining the prospects for continued global warming and climate change."[28] "Stabilization of climate . . . requires that EEI be reduced to approximately zero to achieve Earth's system quasi-equilibrium."[29] As such, EPA must determine how its standards will result in GHG emissions reductions required in order to align with a trajectory of returning CO_2 levels to below 350 ppm by 2100, which would restore the energy balance of Earth.[30]

The transportation sector accounts for approximately 29% of GHG emissions in the U.S as of 2019.[31] According to the EPA, "[t]he transportation sector generates the largest share of greenhouse gas emissions. Greenhouse gas emissions from transportation primarily come from burning fossil fuel for our cars, trucks, ships, trains, and planes."[32] EPA's proposed rule must be crafted so that the GHG emissions that result from the program are in line with the U.S. government's public trust and constitutional obligation to reduce U.S. emissions in line with a <350 ppm CO_2 target by 2100. The proposed rule is not aligned with that standard, nor does it analyze how the emissions it allows from the passenger cars and light duty truck fleets of the transportation sector achieves the overall national emissions reductions necessitated by science and law.

EPA must also disclose how its proposed GHG emission standards would be consistent with achieving the U.S. Nationally Determined Contribution of reducing its net greenhouse gas emissions by 50-52% below 2005 levels by 2030.[33] How is it possible to continue authorizing cars and trucks with internal combustion engines at the levels permitted by the proposed rule given the current climate catastrophe and the U.S. government's commitment to reduce its net GHG emissions by 50-52% below 2005 levels? Experts have opined that it is technically and economically feasible to transition the U.S. off of fossil fuels by 2050.[34] Key actions for this transformation include "begin[ning] large-scale electrification in transportation" in

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[26] *Juliana v. United States*, 217 F. Supp. 3d 1224, 1250 (D. Or. 2016)
[27] *See Assessing "Dangerous Climate Change", supra* note.
[28] von Schuckmann et al., *supra* note .
[29] *Id.*
[30] *Id.*, James Hansen et al., *Target Atmospheric CO_2: Where Should Humanity Aim?* 2 Open Atmospheric Sci. J. 217 (2008).
[31] U.S. EPA, *Sources of Greenhouse Gas Emissions*, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (last visited Sept. 17, 2021).
[32] *Id.*
[33] The United States of America Nationally Determined Contribution, *Reducing Greenhouse Gases in the United States: A 2030 Emissions Target* (April 2021).
[34] *See supra* note 5 .

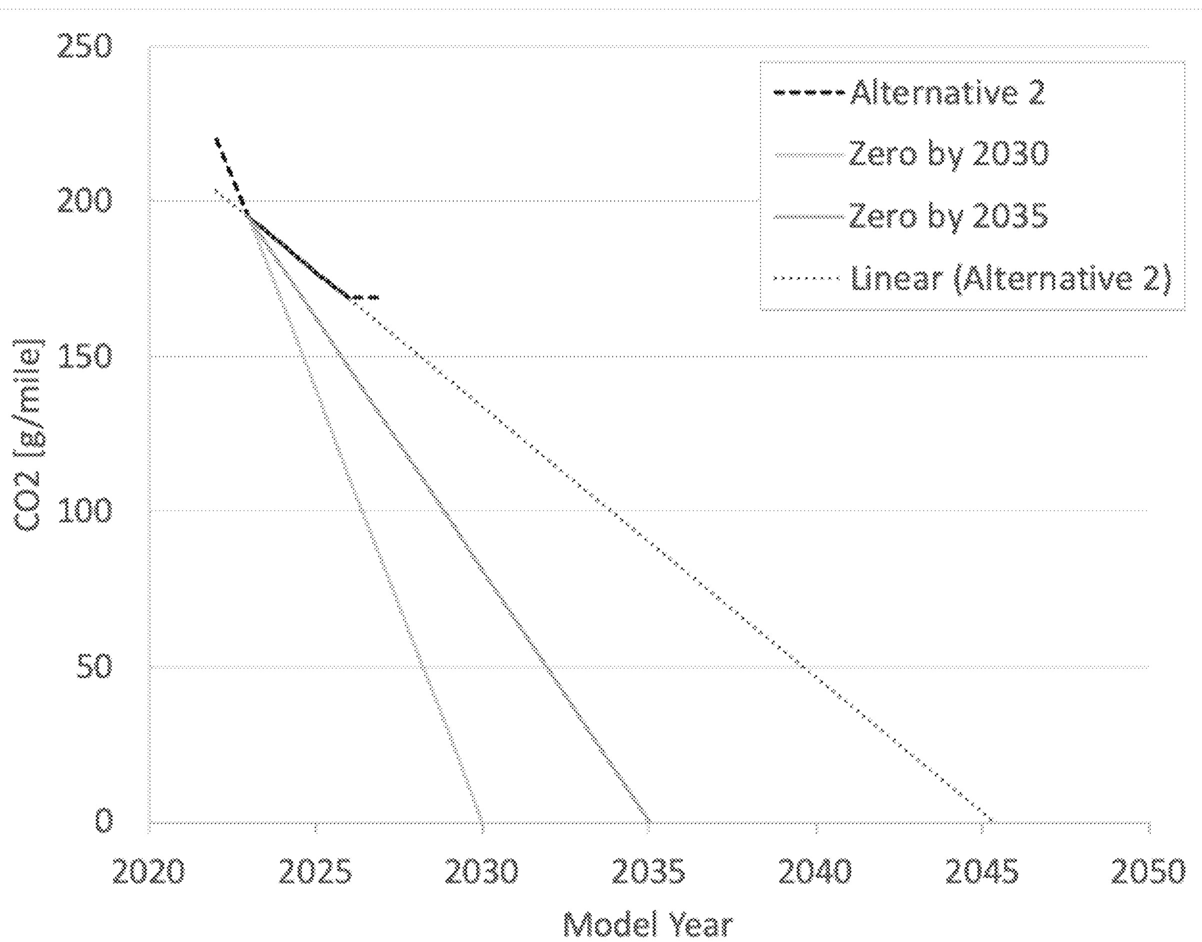
the 2020s.[35] It is now 2021 and EPA has no plan in place for how it intends to ensure electrification of transportation and elimination of GHG emissions from the transportations activities that are within its regulatory control. Experts say that the entire new vehicle fleet can and should be electric by 2030 and 2035 for heavy duty trucks at the latest. EPA must utilize this regulatory process to ensure that its proposed GHG emission standards follows the advice of what experts say are needed to decarbonize and electrify the national transportation system. Under the current proposal, several car manufacturers are able to sell zero BEVs through 2026 and buy offsets from companies like Tesla. This system of allowing for an GHG emissions average by fleet, the purchasing of offsets form other companies, and no minimum requirements for the percentage of sales that are zero emissions by certain years does not demonstrate that the 2030 or 2035 targets would be met.

EPA's GHG Emission Standards Must Facilitate Decarbonization of the Nation's Transportation System.

Decarbonization of the transportation sector is critical to achieving GHG emission reductions goals and thus EPA's emissions standards must ensure they facilitate, rather than inhibit, decarbonization goals. In fact, experts have opined that "[t]ransportation electrification is the most critical sector to achieve these electrification goals in due to the volume of liquid fuels it currently consumes."[36] Energy experts have performed numerous pathway analyses which lay out the roadmap for what needs to be done to decarbonize all sectors of the U.S. economy, including transportation. EPA must begin large-scale electrification of the U.S. transportation system this decade [2020s], with near 100% sales of key electrified technologies by 2030—far more than EPA's projection "that during the four-year ramping up of the stringency of the CO_2 standards, the proposed standards could be met with gradually increasing sales of plug-in electric vehicles in the U.S., up to about 8 percent market share (including both electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) by MY 2026."[37] For instance, a minimum of 80-100% of new vehicles sold by 2030 should be electric or hydrogen fueled.

To enable and facilitate this transformation, EPA's regulatory action must demonstrate that its standards will result in a zero emission standard no later than 2030 for at least passenger vehicles and 2035 for heavy duty trucks. The RIA does not demonstrate that. Instead, it suggests that even for Alternative 2 (the most stringent standard), a zero emission result would not be achieved until approximately 2045 if the current emissions standards are carried out in a linear fashion. In order to reach zero fleet emissions in 2030 and 2035, assuming a linear decrease in CO_2 [g/mile] from the projected Alternative 2 target of 195 g/mile in 2023, the projected fleet average target levels for 2026 would need to be ~111 and ~146 CO2 [g/mile], respectively. The graph below carries the Alternative 2 line of Table 8 (RIA at xxi) toward a zero emissions standard and adds standards that are consistent with the minimum EPA should be doing to achieve the necessary emission reductions from the transportation sector. The RIA suggests that the emissions standards after MY2026 could result in steeper reductions, but it does not explain why, how or when those decisions will be made, and why they are not being made now given the technical and economic feasibility, the climate emergency, and the auto manufacturer's capacity to move more quickly.[38]

[35] Ben Haley et al., *350 ppm Pathways for the United States* 15 (2019).
[36] *Id.* at 38.
[37] 86 Fed. Reg. 43,731.
[38] The RIA only states: "As in many prior EPA mobile source rulemakings, the decision on what standard to set is largely based on the availability, capability, and cost of the emissions control technology along with the need for



EPA should also be working with the Department of Transportation and other agencies to encourage building markets to electrify vehicles of all types and ensure that the transportation system has the infrastructure needed to accommodate electrified transportation. Electrification will require integrated planning to ensure that new resources are developed to meet the growing demand, to plan distribution system upgrades and charging infrastructure, and to leverage the ability of new electric loads to operate flexibly. In addition, EPA must ensure that its policies promote mobility and alternative and equitable forms of transportation, reduce vehicle miles traveled, and that its investments do not needlessly invest in a transportation system that puts more cars on the road.

More stringent GHG emission standards will provide greater economic benefits

EPA's own analysis demonstrates that Alternative 2 provides the most economic benefits and savings for consumers. However, Alternative 2 is based on 2012 rule standards carried out

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reductions of GHG and the benefits of doing so. This proposal would also establish a path toward more significant reductions in the years following 2026." RIA at 2-1. What is that path?

linearly to 2026, which is now nearly a decade old and does not account for the latest science and improvements in EV technology as well as decreased costs for EVs. RIA at xx. The availability, capability, and cost of technology reducing emissions in this part of the transportation sector all favor more stringent standards tied to a 2030 zero emissions target. EPA does not explain why it is not pursuing more significant reductions *now* rather than in the years following 2026. RIA at 2-1.

EPA needs to evaluate an alternative that is in line with the best climate science for returning to <350 ppm CO_2 by 2100, which requires nearly complete decarbonization of all energy sectors by 2050 and a zero emission standard for most new vehicles by 2030. The Biden administration has committed to a zero emission new vehicle fleet by 2035, but the proposed rule does not demonstrate how the rule will achieve that. EPA admits in the RIA, that none of the alternatives it considered are as rigorous enough to match what is possible from the auto industry in terms of EV penetration. It is EPA's job to do as much as it can to push the transition to zero emissions to protect the air and climate for children and future generations. It should not be waiting for the market to decide when to transition, but leading the way.

The Issue with Credits and Offsets

The RIA demonstrates that the new rule provides credits for natural gas vehicles that incentivize those vehicles when all vehicles need to move completely away from fossil fuels. RIA at 1-14.

EPA also incentivizes BEVs with credits and multipliers, but allows other manufacturers to continue producing entire fleets of ICEs. For instance Mitsubishi and Subaru will produce zero BEVs by MY2026, but Tesla will be able to sell its credits for having a 100% BEV fleet to those manufacturers. This system of standards needs to change to transition the fleet at a faster pace toward the 2030 standard as described above.

Manufacturers are allowed to take credits to offset their emissions standards by improving their air conditioning systems. Both need to occur. One should not lessen the need to do the other. Those credits should be eliminated and both should be required because "The technological achievements already developed and already increasing in application to vehicles within the current new vehicle fleet (Chapter 2.3) will enable the industry to achieve the proposed standards even without the development and implementation of additional technologies.". RIA at 2-5, 2-6.

The Economic Analysis is Old

The RIA concedes that it is relying on data from 2016 and other outdated analysis and IAM that does not account for actual costs and benefits and the feasibility of BEVs. That should be addressed in the new rule, which should be more stringent than what is proposed here.

EPA Should Not Place the Burdens of Climate Change on Youth and Future Generations

The EPA's RIA violates the constitutional rights of youth and future generations by placing the physical and financial burden of climate change on them. Most notably, the RIA (1) fails to include a complete health and environmental assessment of GHG emissions that are explicitly authorized under the proposed rule; (2) fails to account for the true cost of authorizing GHG emissions from passenger vehicles and light trucks placing greater economic and other burdens on children and future generations; and (3) uses discount rates that undervalue the interests and rights of today's youth and future generations.

Youth and Future Generations are Already Facing a Health Crisis as a Result of Climate Change

Climate change is causing a public health emergency that is adversely impacting the physical and mental health of children through, among other impacts, extreme weather events, increased heat exposure, decreased air quality, altered infectious disease patterns, and food and water insecurity.[39] These exact types of impacts are *already* occurring at present levels of heating with regular frequency.

Increased heat exposure is particularly devastating for children at multiple stages of development. Infant mortality increases 25% on extremely hot days with the first seven days of life representing a period of critical vulnerability.[40] Extreme heat places young children at higher risk of kidney and respiratory disease as well as fever and electrolyte imbalance.[41] Heat illness is also a leading cause of death and illness in high school athletes with nearly 10,000 episodes occurring annually.[42]

Children's growing bodies are more susceptible to environmental irritants, and these irritants are increasing due to climate change. Over eight percent of children suffer from allergic rhinitis, and the ragweed pollen season in North America has grown 13-27 days longer since 1995 due to higher temperatures and greater CO_2 levels.[43] As wildfire seasons grow in length and

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[39] Lancet Countdown on Health and Climate Change, Policy Brief for the United States of America, Am. P. Health Ass'n. 6 (2019); S. Ahdoot & S.E. Pacheco, Global Climate Change and Children's Health, 136 Pediatrics e1468, e1468 (2015) ("The effects of climate change on child health include physical and psychological sequelae of weather disasters, increased heat stress, decreased air quality, altered disease patterns of some climate-sensitive infections, and food, water, and nutrient insecurity in vulnerable regions.").

[40] Xavier Basagaña et al., Heat Waves and Cause-specific Mortality at all Ages, 22 Epidemiology 765, 769 (2011) ("In infants, the effect of heat was particularly strong, with mortality increases of 25% when considering only the first hot day."); *see also*, Linda Giudice, A Clarion Warning About Pregnancy Outcomes and the Climate Crisis, 3 JAMA Network Open e208811, e208811 (2020) (noting that "exposures mainly in the third trimester (or averaged across gestation) to $PM_{2.5}$, O_3, and heat, alone or together, are associated with [preterm birth, low birth weight, and stillbirth] in the vast majority of studies analyzed").

[41] Nick Watts et al., The 2019 Report of The Lancet Countdown on Health and Climate Change: Ensuring That the Health of a Child Born Today Is Not Defined by a Changing Climate, 394 The Lancet 1836, 1841 (2019).

[42] J. Gilchrist et al., Heat Illness Among High School Athletes—United States, 2005–2009, 59 CDC Morbidity & Mortality Weekly Report 1009, 1009 (2010) ("Heat illness during practice or competition is a leading cause of death and disability among U.S. high school athletes[]. . . . The average [time-loss heat illness] corresponds to a weighted average annual estimate of 9,237 illnesses nationwide."); *see also*, Perry Sheffield et al., Climate Change and Schools: Environmental Hazards and Resiliency, 14 Int'l J. Env't Res. & Pub. Health 1397, 1399 (Nov. 16, 2017) (noting that climate change-induced extreme heat "is of particular concern for student athletes").

[43] Allergy Facts, American College of Allergy, Asthma, & Immunology (Jan. 9, 2018) ("In data published from the 2014 National Health Interview Survey (NHIS), 8.4% of US children under age 18 suffered from hay fever[.]"); Lewis Ziska et al., Recent Warming by Latitude Associated with Increased Length of Ragweed Pollen Season in Central

severity across the western U.S., exposed children suffer substantial eye symptoms, as well as upper and lower respiratory symptoms, which lead to increased rates of asthma-related hospitalizations and emergency room visits.[44] Extreme weather events have negative impacts on children's mental health as well as their physical health due to family loss or separation; school interruption; scarcity of food, water, and shelter; and public service outages during crucial stages of their growth and development.[45] Expert reports written by Dr. Susan Pacheco, Dr. Jerome Paulson, and Dr. Howard Frumkin are attached to this Comment, providing more detail on these extreme, particularized impacts of climate change on children's health. In addition to scientific experts, judicial systems around the world are recognizing the increased, foreseeable risk of severe health issues that children and future generations face from climate change impacts.[46]

The draft RIA is not as "extensive as practicable" as it contains no thorough assessment of the aforementioned health and environmental impacts on children from GHG emissions accumulating from passenger cars and trucks, intentionally ignoring the well-known and scientifically proven impacts on youth.[47] Instead, the RIA focuses on the negative health and environmental impacts from exposure to non-GHG pollutants including particulate matter, ozone, nitrogen oxides, sulfur oxides, carbon monoxide, air toxics, and other impacts from exposure to traffic, all of which are important to assess, but not to the exclusion of health specific impacts from GHG emissions.[48] Given the severity of the climate crisis, the U.S. government's long-standing practice of emitting massive amounts of GHGs, and the resulting increase in Earth's energy imbalance, every ton of GHGs emitted matters immensely.[49] While exposure to non-GHG pollutants is an important part of the analysis, EPA has no basis for its statement that "[t]hese [GHG] pollutants will not be directly regulated by the[se] standards."[50] Passenger cars and trucks are not allowed on the roads unless they meet EPA's regulatory standards and thus EPA is directly responsible for the GHG emissions that result from these sources.

North America, 108 Proc. Nat'l Acad. Sci. 4248, 4248 (2011) ("Overall, these data indicate a significant increase in the length of the ragweed pollen season by as much as 13–27 [days] at latitudes above ~44°N since 1995.").

[44] Nino Künzli et al., *Health Effects of the 2003 Southern California Wildfires on Children*, 174 Am. J. Respiratory & Critical Care Med. 1221, 1224 (2006) ("Having fire smoke smell indoors for more than 6 [days] was associated with more than fourfold higher rates of eye symptoms, approximately threefold increased rates of dry cough and sneezing, and more than twofold higher rates of cold, sore throat, wet cough, medication use, physician visits, and missed school due to symptoms. . . . Asthma attacks increased 63%."); *see also*, Watts et al., *supra* note , at 1837 ("Through adolescence and beyond, air pollution – principally driven by fossil fuels, and exacerbated by climate change – damages the heart, lungs, and every other vital organ. These effects accumulate over time[.]").

[45] Daniel Martinez Garcia & Mary C. Sheehan, *Extreme Weather-Driven Disasters and Children's Health*, 46 Int'l J. Health Services 79, 88 (2016) ("Abrupt disruptions in a child's life such as family loss or separation; school interruption; changes in food and water supply and shelter conditions; and public service outages may cause direct acute shock and other emotional trauma, as well as longer-term indirect effects.").

[46] *See, e.g.*, Sharma et al. v Minister for the Environment, [2021] FCA 560, ¶¶225, 235, 246 (Austl.); Klimaatzaak v Belgium et al., Tribunal de Premiére Instance [Civ.] [Tribunal of First Instance] Brussels, 4 ch. Jun. 17, 2021, 63 (Belg.).

[47] *RIA* at 7-1 to 7-15.

[48] *Id.*

[49] IPCC, *Summary for Policymakers, in* Climate Change 2021: The Physical Science Basis SPM-37 (In Press) ("Every tonne of CO_2 emissions adds to global warming").

[50] *RIA* at 7-1.

The RIA Fails to Account for the True Costs of Climate Change

The extraordinary costs of climate change are well documented and can be measured in both economic terms and loss of life. A segment of climate-related damages comes from extreme weather events, which are increasing in severity due to climate change. The NOAA National Centers for Environmental Information states that "[t]he U.S. has sustained 298 weather and climate disasters since 1980 where overall damages/costs reached or exceeded $1 billion (including CPI adjustment to 2021). **The total cost of these 298 events exceeds $1.975 trillion**."[51] In the 2010s, there were 123 climate disaster events, resulting in 5,224 deaths, with a price tag of $844.7 billion.[52] Just this year, as of July 9, 2021, "there have been 8 weather/climate disaster events with losses exceeding $1 billion each to affect the United States. These events included 1 drought event, 2 flooding events, 4 severe storm events, and 1 winter storm event. Overall, these events resulted in the deaths of 331 people and had significant economic effects on the areas impacted."[53] These kinds of extraordinary (and deadly) costs from what the U.S. government calls "climate disasters" dwarf the "costs of compliance" with the proposed rule must be considered when conducting an economic impact analysis that is "as extensive as practicable."[54]

The RIA Uses Discount Rates that Infringe the Constitutional Rights of Youth and Future Generations

The RIA purposely devalues the long-term effects of these climate-induced harms that today's young people and future generations will endure throughout their lives.[55] By incorporating higher than scientifically supported discount rates into its analysis, the EPA makes a value judgment that these intense negative health and economic burdens on youth and future generations matter very little, if at all. The problems with this approach have been summarized by the late economist Frank Ackerman in his expert report in the *Juliana* litigation:

> The treatment of discounting by [the U.S. Government] frames their economic analysis of long-term problems such as climate change and has resulted in a policy or practice by [the government] that deliberately devalues the climate harms [the government] knew these Youth Plaintiffs will experience over the long term. Discount rates have immense influence on the results of economic analyses, particularly in an intergenerational context. How much less are future costs and benefits worth today, solely because they will occur in the future? If a high discount rate is used, the costs and benefits that will be experienced 100 years from now are worth almost nothing today, suggesting that climate mitigation (or other policies that benefit future generations) are not worth spending much on today. At a low discount rate, such as the 1.4% annual rate adopted by the Stern Review (Stern

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[51] NOAA, Nat'l Centers for Environmental Information, *Billion-Dollar Weather and Climate Disasters: Overview*, https://www.ncdc.noaa.gov/billions/ (emphasis in original) (last visited Sept. 21, 2021).

[52] *Id.*

[53] *Id.*

[54] 42 U.S.C. § 7617(c)(1), (d).

[55] *See* Expert Report of Susan E. Pacheco, MD and Jerome A. Paulson, MD, FAAP, at 26-29, *Juliana v. United States*, No. 6:15-cv-01517 (D. Or. Jun. 28, 2018) (documenting the severe, long-term impacts climate change will have on children's lifelong success and development) [Attachment 5]; *see also*, Expert Report of Howard Frumkin, MD, MPH, DrPH, *Juliana v. United States*, No. 6:15-cv-01517 (D. Or. Jun. 28, 2018) [Attachment 6].

> 2007), the present value of future impacts is much more substantial, endorsing policy-making as if the future mattered. Within the economic debates over discount rates, there are many strong rationales for very low, and even zero, discount rates. This is important because a very low discount rate is required in order to recognize the importance of climate impacts on future generations and their wellbeing in [the government's] climate and energy policy.[56]

Nobel Laureate economist, Dr. Joseph Stiglitz, has been also been advising the U.S. government for years (including in 2021) to lower the discount rate in order to account for the high risk of climate harms and for the need to protect children and future generations. Dr. Stiglitz believes the U.S. government's policies that discount children's future "at inappropriately high rates continue to steer America on the path of incalculable losses and away from that more demanding and sane course."[57]

Government agencies have also long recommended the use of lower discount rates when considering rules and policies that will have far-reaching intergenerational effects. The U.S. General Accounting Office (renamed the Government Accountability Office in 2004) indicated in 1991 that "sensitivity analysis should be used to address issues such as . . . intergenerational effects of policies on human life[,]"[58] noting that "[t]his approach can yield an effective real discount rate very close to zero[.]"[59] In 2003, Office of Management and Budget ("OMB") similarly suggested that, "[i]f your rule will have important intergenerational benefits or costs[,] you might consider a further sensitivity analysis using a lower but positive discount rate[.]"[60] EPA is incorrect that it is somehow legally constrained from using lower discount rates. As the EPA puts it in its 2010 guidelines for Preparing Economic Analyses,

> OMB's *Circular A-4* (2003) *requires* the use of constant 3 percent and 7 percent for both intra- and intergenerational discounting for benefit-cost estimation of economically significant rules *but allows for* lower, positive consumption discount rates, perhaps in the 1 percent to 3 percent range, if there are important intergenerational values.[61] (emphasis added)

OMB *Circular A-4*, promulgated pursuant to an Executive Order, cannot be used as a means for EPA to deviate from its statutory obligation to promote public health and welfare and to conduct an economic impact assessment that is "as extensive as practicable." OMB has no statutory authority to mandate the discount rates being implemented by EPA. If the science supports use of discount rates lower than 2.5%, 3%, 5% and 7%, which it clearly does as EPA itself acknowledges, then that is what EPA must use.

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[56] Expert Report of Frank Ackerman, at 2, *Juliana v. United States*, No. 6:15-cv-01517 (D. Or. Jun. 28, 2018) [Attachment 7].
[57] Expert Report of Joseph E. Stiglitz, Ph.D., at ¶79, *Juliana v. United States*, No. 6:15-cv-01517 (D. Or. Jun. 28, 2018) [Attachment 8].
[58] U.S. General Accounting Office, *Discount Rate Policy* 9 (May 1991).
[59] *Id.* at 11.
[60] Office of Management and Budget, *Circular A-4*, at 36 (2003).
[61] U.S. EPA, *Ch. 6 Discounting Future Benefits and Costs*, *in* Guidelines for Preparing Economic Analyses 6-15 (2010).

By using outdated and scientifically unsupported discount rates, rather than committing to and implementing the use of a specific, lower discount rate for policies that implicate future generations, the EPA is perpetuating the tremendous burdens being placed on young people and future generations. These young people and future generations cannot afford for the EPA to make the same mistake with its newest GHG standards. The bottom line is that in order to treat a life in the future equally to a life today, we must take into account all the services that a stable climate system has provided for past and present generations, services that are at severe risk of widespread diminishment for future generations. When taking these considerations into account, economic and scientific analyses strongly indicate that future generations will be even worse off than us (suggesting a negative discount rate) and at best would be about as well off as those of us living today (suggesting a discount rate of zero).

"If our impacts on future generations matter, then the appropriate discount rate for climate costs and benefits needs to be very low, probably near zero, an argument made effectively in the Stern Review (Stern 2007) and other sources."[62] As part of its RIA, EPA should conduct a sensitivity analysis with a discount rate of zero with much more stringent alternatives to the proposed rule that will lead to a zero emissions standard for all new vehicles by 2030 and 2035 at the latest. Then EPA can determine the true impacts of its proposed rule and much better alternatives for children and future generations.

Conclusion

Given the fact that U.S. government conduct has resulted in a quarter of all global GHG emissions that are causing the current climate catastrophe, it is well past time for the EPA to take all steps within its power to ensure its GHG emission standards for cars and trucks are aligned with with the best available science and are eliminating tailpipe GHG emissions from all new vehicles by 2030 or 2035 at the latest for heavy duty vehicles, in line with eliminating total U.S. emissions by close to 100% by 2050, placing the U.S. on an emissions trajectory consistent with returning atmospheric CO_2 to below 350 ppm by 2100, or otherwise explain why those reductions cannot be met. Without immediate effective action, our children and future generations will continue to suffer injury with long-lasting and potentially irreversible consequences.[63] Moreover, all young people seeking environmental and climate justice, especially youth from frontline and environmental justice communities that have contributed the least to emissions and have long suffered from systemic environmental racism and social and economic injustices, must have their voices heard in developing climate change policies.

Thank you for your consideration. Please include all cited evidence in the administrative record. We are happy to provide any of the cited evidence on request. Please send us a response to our comments and decision documents to the address and email listed below.

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[62] Expert Report of Frank Ackerman, *supra* note , at 7.

[63] *See Assessing "Dangerous Climate Change"*, *supra* note ; James Hansen et al., *Ice Melt, Sea Level Rise and Superstorms: Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2°C Global Warming Could be Dangerous*, 16 Atmos. Chem. & Phys. 3761 (2016); U.S. Global Change Research Program, *Fourth National Climate Assessment, Vol. II* (2018).

Sincerely,
/s/

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julia@ourchildrenstrust.org

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Attachment 1: Our Children's Trust, *Government Climate and Energy Policies Must Target <350 ppm Atmospheric CO_2 by 2100 to Protect Children and Future Generations* (Mar. 2021).

Attachment 2: Ben Haley et al., *350 ppm Pathways for the United States, Executive Summary* (2019). Full report available at https://www.ourchildrenstrust.org/s/350-PPM-Pathways-for-the-United-States-gk6k.pdf.

Attachment 3: Ben Haley et al., *350 ppm Pathways for Florida*, Executive Summary and U.S. data from the Technical Supplement (2020). Full report available at https://www.ourchildrenstrust.org/s/350-PPM-Pathways-Florida-Report-pa2t.pdf.

Attachment 4: Mark Z. Jacobson, *Zero Air Pollution and Zero Carbon From All Energy Without Blackouts at Low Cost in the Whole United States* (2021).

Attachment 5: Expert Report of Susan E. Pacheco, MD and Jerome A. Paulson, MD, *Juliana v. United States*, No. 6:15-cv-01517 (D. Or. Jun. 28, 2018).

Attachment 6: Expert Report of Howard Frumkin, MD, MPH, DrPH, *Juliana v. United States*, No. 6:15-cv-01517 (D. Or. Jun. 28, 2018).

Attachment 7: Expert Report of Frank Ackerman, *Juliana v. United States*, No. 6:15-cv-01517 (D. Or. Jun. 28, 2018).

Attachment 8: Expert Report of Joseph E. Stiglitz, Ph.D., *Juliana v. United States*, No. 6:15-cv-01517 (D. Or. Jun. 28, 2018).

Attachment 1

Our Children's Trust Youth v. Gov

Government Climate and Energy Policies Must Target <350 ppm Atmospheric CO_2 by 2100 to Protect Children and Future Generations (March 2021)

INTRODUCTION

Human laws can adapt to nature's laws, but the laws of nature will not bend for human laws. Government climate and energy policies **must** be based on the best available science to protect our climate system and vital natural resources on which human survival and welfare depend, and to ensure the fundamental rights of young people and future generations are protected.

Because carbon dioxide (CO_2) is the primary driver of Earth energy imbalance (EEI), climate destabilization, and ocean warming and acidification, all government policies regarding CO_2 emissions and CO_2 sequestration should be aimed at reducing global CO_2 concentrations **below 350 parts per million (ppm) by 2100**. Global mean atmospheric CO_2 levels, as of 2020, are approximately 412 ppm and rising.[1] With timely action, an emission reductions and sequestration pathway back to <350 ppm could limit peak warming to approximately 1.3°C this century and stabilize long-term heating this century at ~1°C above pre-industrial temperatures with further reductions next century. The temperature of the Earth, much like sea level rise, is a measurable indicator of the CO_2 problem, but it is not a good metric for solving it. EEI and CO_2 levels provide measurable standards, with CO_2 emission reductions and sequestration the measurable means to meet those standards.

As explained in more detail below, there are numerous scientific bases and lines of evidence supporting setting <350 ppm by 2100 as the uppermost safe limit for atmospheric CO_2 concentrations and global warming. Beyond 2100, atmospheric CO_2 may need to return to well below 350 ppm and closer to the preindustrial level of ~280 ppm to prevent the complete melting of Earth's ice sheets and protect coastal cities from sea level rise. Fortunately, it is still not only technically and economically feasible to return to <350 ppm by 2100, but transitioning to clean energy sources will provide significant economic and public health benefits and improve quality-of-life.

WHY GOVERNMENTS MUST AIM FOR <350 PPM AND RESTORING EARTH ENERGY BALANCE

Three lines of robust and conclusive scientific evidence, based on the paleo-climate record and real-world observations, show that above an atmospheric CO_2 concentration of 350 ppm there is: 1) significant Earth energy imbalance; 2) massive ice sheet destabilization and sea level rise; and 3) ocean warming and acidification resulting in the bleaching death of coral reefs and other marine life.

[1] Ed Dlugokencky & Pieter Tans, NOAA/GML, www.esrl.noaa.gov/gmd/ccgg/trends/.

1) Earth Energy Imbalance

Scientists say the "Earth energy imbalance (EEI) is the most critical number defining the prospects for continued global warming and climate change."[2] "Stabilization of climate, the goal of the universally agreed United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and the Paris Agreement in 2015, requires that EEI be reduced to approximately zero to achieve Earth's system quasi-equilibrium."[3] Earth's energy flow is significantly out of balance. Because of a buildup of CO_2 (and to a lesser extent other greenhouse gases) in our atmosphere, due to human activities, primarily the burning of fossil fuels and deforestation,[4] more solar energy is retained in our atmosphere and less energy is released back into space.[5] (Figure 1.)[6] The measured imbalance from 2010-2018 (0.87 ± 0.12 Wm^{-2}) was approximately double the imbalance from 1971-2018.[7]

Returning CO_2 concentrations to below 350 ppm would restore the energy balance of Earth by allowing as much heat to escape into space as Earth retains, an important historic balance that has kept our planet in the sweet spot for the past 10,000 years, supporting stable sea levels and coastlines, enabling productive agriculture, and allowing humans and other species to thrive.[8] The paleo-climate record shows that CO_2 levels, temperature, and sea level all move together (see Figure 2). Humans have caused CO_2 levels to shoot off the chart (circled in red), rising to levels unprecedented over the past 3 million years, and causing the Earth energy imbalance.[9]

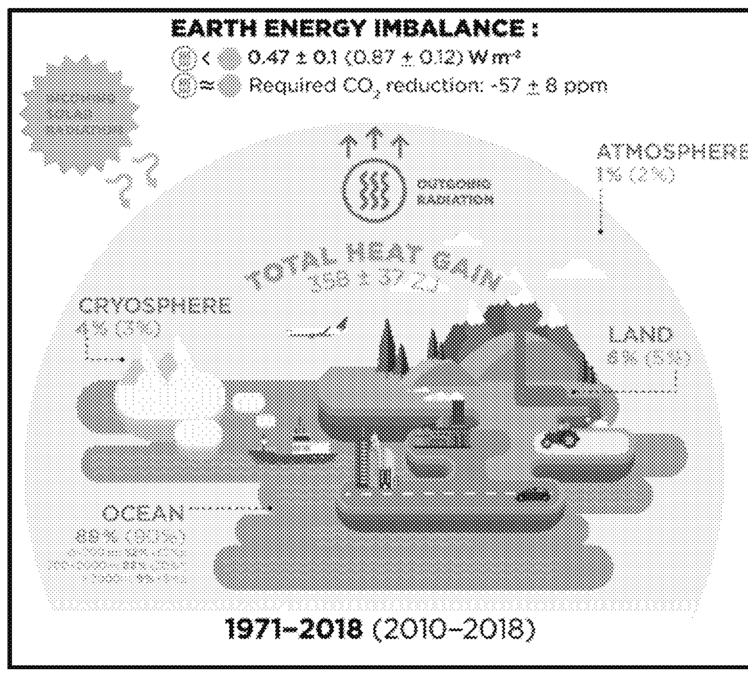

Figure 1: Earth heat inventory for Earth energy imbalance at the top of the atmosphere.

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[2] Karina von Schuckmann et al., *Heat Stored in the Earth System: Where Does the Energy Go?*, 12 Earth Syst. Sci. Data. 2013 (2020) [hereinafter *Heat Stored in the Earth System*] (written by 38 international experts, including lead IPCC authors).

[3] *Id.*

[4] IPCC, *Summary for Policymakers, in* Climate Change 2014: Synthesis Report (2014).

[5] James Hansen et al., *Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, 8 PLOS ONE e81648 (2013) [hereinafter *Assessing "Dangerous Climate Change"*].

[6] von Schuckmann, *Heat Stored in the Earth System.*

[7] *Id.*

[8] James Hansen, *Storms of My Grandchildren* 166 (2009).

[9] M. Willeit et al., *Mid-Pleistocene Transition in Glacial Cycles Explained by Declining CO_2 and Regolith Removal*, 5 Science Advances eaav7337 (2019).

2) Ice Sheets and Sea Level Rise

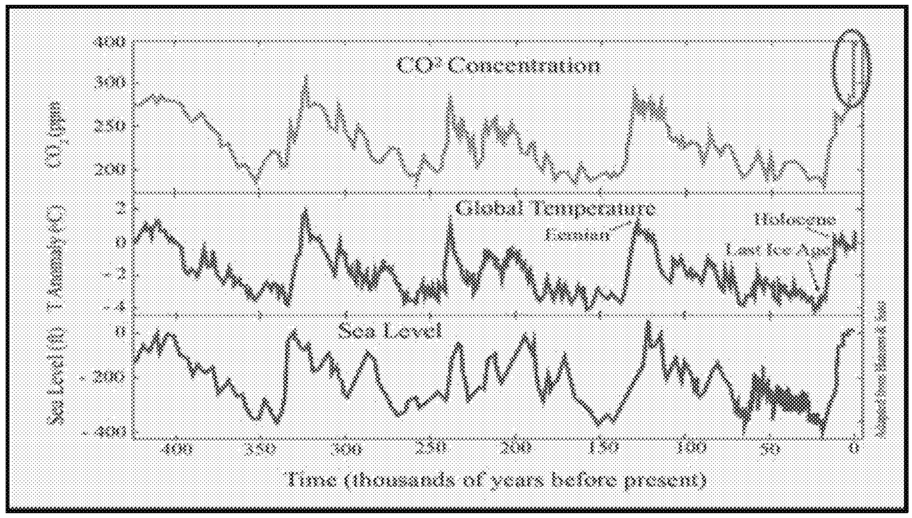

Figure 2: Evidence from the paleo-climate record showing the relationship between CO_2 concentration, global temperature, and sea level.

The last time the ice sheets appeared stable in the modern era was in the 1980s when the atmospheric CO_2 concentration was below 350 ppm. The consequences of >350 ppm and >1°C of warming are already visible, significant, and dangerous for humanity. With just over a global average 1°C of warming, glaciers in all regions of the world are shrinking, and the rate at which they are melting is accelerating.[10] Large parts of the Greenland and Antarctic ice sheets, which required millennia to grow, are teetering on the edge of irreversible disintegration, a point that, if reached, would lock-in major ice sheet mass loss, sea level rise of many meters, and worldwide loss of coastal cities – a consequence that would be irreversible on any timescale relevant to humanity (see Figure 3).[11] Greenland's ice sheet melt is currently occurring faster than anytime during the last three and a half centuries, with a 33% increase alone since the 20th century.[12] From 1994 to 2017, the Earth lost 28 trillion tonnes of ice, with the rate of ice loss increasing by 57% compared to the 1990s.[13] The paleo-climate record shows the last time atmospheric CO_2 levels were over 400 ppm, the seas were **70 feet higher** than they are today and heating consistent with CO_2 concentrations as low as 450 ppm may have been enough to melt almost all of Antarctica.[14] While many experts are predicting multi-meter sea level rise this century, even NOAA's modest estimate of 5-8.2 feet (1.5-2.5 m) global mean rise by 2100[15] would impact millions of Americans (see Figure 4).[16]

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[10] M. Zemp et al., *Global Glacier Mass Changes and their Contributions to Sea-Level Rise from 1961-2016*, 568 Nature 382 (2019); B. Menounos et al., *Heterogeneous Changes in Western North American Glaciers Linked to Decadal Variability in Zonal Wind Strength*, 46 Geophysical Research Letters 200 (2019).

[11] Hansen, *Assessing "Dangerous Climate Change,"* at 13; *see also* James Hansen et al., *Ice Melt, Sea Level Rise and Superstorms; Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2 °C Global Warming Could be Dangerous*, 16 Atmos. Chem. & Phys. 3761 (2016) [hereinafter *Ice Melt, Sea Level Rise and Superstorms*].

[12] L.D. Trusel et al., *Nonlinear Rise in Greenland Runoff in Response to Post-industrial Arctic Warming*, 562 Nature 105 (2018).

[13] T. Slater et al., *Earth's Ice Imbalance*, 15 The Cryosphere 233 (2021).

[14] James E. Hansen, *Declaration in Support of Plaintiffs, Juliana v. United States*, No. 6:15-cv-01517-TC, 14 (D. Or. Aug. 12, 2015); IPCC, *Chapter 6.3.2, What Does the Record of the Mid-Pliocene Show?, in* Climate Change 2007: The Physical Science Basis (2007); Dowsett & Cronin, *High Eustatic Sea Level During the Middle Pliocene: Evidence from the Southeastern U.S. Atlantic Coastal Plain*, 18 Geology 435 (1990); N.J. Shackleton et al., *Pliocene Stable Isotope Stratigraphy of Site 846*, 138 Proceedings of the Ocean Drilling Program, Scientific Results 337 (1995).

[15] NOAA, *Global and Regional Sea Level Rise Scenarios for the United States* (2017) (intermediate-high to extreme global mean sea level rise scenarios).

[16] NOAA, Examining Sea Level Rise Exposure for Future Populations, https://coast.noaa.gov/digitalcoast/stories/population-risk.html.

Figure 3: Antarctic melt water from the Nansen ice shelf.

Many climate models represent sea level rise as a gradual linear response to melting ice sheets, but the historic climate record shows something very different. In reality, seas do not rise slowly and predictably but rather in pulses as ice sheets destabilize.[17] Scientists believe we still have a chance to preserve the large ice sheets of Greenland and Antarctica and most of our shorelines and ecosystems if we restore Earth's energy balance and return to below 350 ppm, thereby limiting longer-term warming by the end of the century to no more than 1°C above pre-industrial levels (short-term warming will inevitably exceed 1°C but must not exceed 1°C for more than a short span of years rather than multiple decades or centuries).

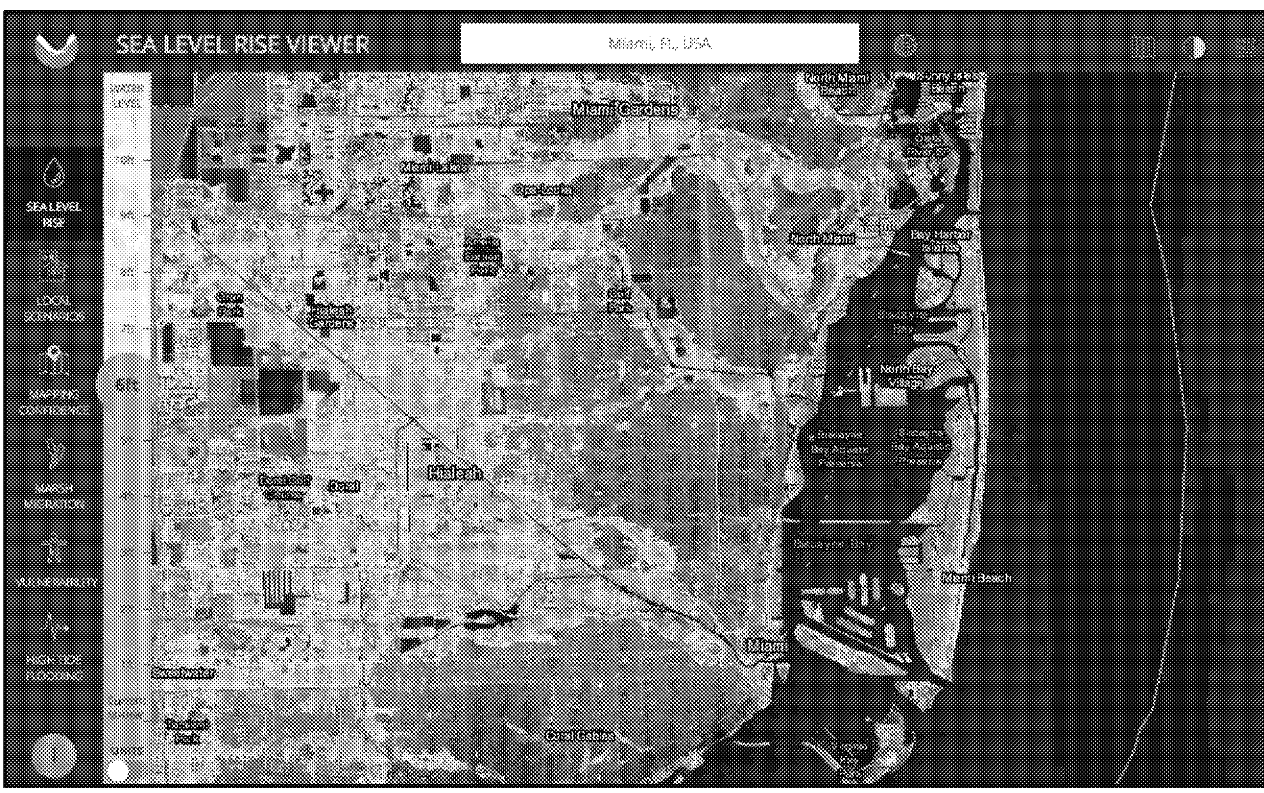

Figure 4: South Florida, including Miami, will face significant inundation with 6 feet of sea level rise.

[17] H.R. Wanless, et al., *Dynamics and Historical Evolution of the Mangrove/Marsh Fringe Belt of Southwest Florida, in Response to Sea-level History, Biogenic Processes, Storm Influences and Climatic Fluctuations*. Semi-annual Research Report (June 1993 to February 1994); Hansen, *Ice Melt, Sea Level Rise and Superstorms*, at 3761; Hansen, *Assessing "Dangerous Climate Change,"* at 20.

3) Ocean Warming and Acidification

Less than 350 ppm is the best scientific standard to protect oceans and marine life. Our oceans have absorbed about 90% of the excess heat in the atmosphere trapped by greenhouse gases (see Figure 5) as well as approximately 30% of CO_2 emitted into the atmosphere, causing ocean temperatures to surge and the ocean to become more acidic.[18] Indeed, our oceans are warming much more rapidly than previously-thought.[19] In 2020, the oceans absorbed 20 sextillion joules of heat due to climate change and warmed to record levels. The quantity of warming, 20,000,000,000,000,000,000,000 joules, is equivalent to the amount of energy from 10 Hiroshima atomic bombs being released every second of the year or to heat 1.3 billion kettles of water.[20] Many marine ecosystems, and particularly coral reef ecosystems, cannot tolerate the increased warming and acidity of ocean waters that result from increased CO_2 levels.[21] At today's global mean CO_2 concentration, around 412 ppm, critically important ocean ecosystems, such as coral reefs, are rapidly declining and will be irreversibly damaged from high ocean temperatures and repeated mass bleaching events if we do not quickly curtail emissions (see Figures 6 and 7).[22] According to the Intergovernmental Panel on Climate Change (IPCC), bleaching events are occurring more frequently than the IPCC previously projected and 70-90% of the world's coral reefs could disappear as soon as 2030 (the IPCC also predicts >99% of coral reefs will die with 2°C warming).[23] The 2018 National Climate Assessment acknowledged that coral reefs in Florida, Hawaii, Puerto Rico, and the

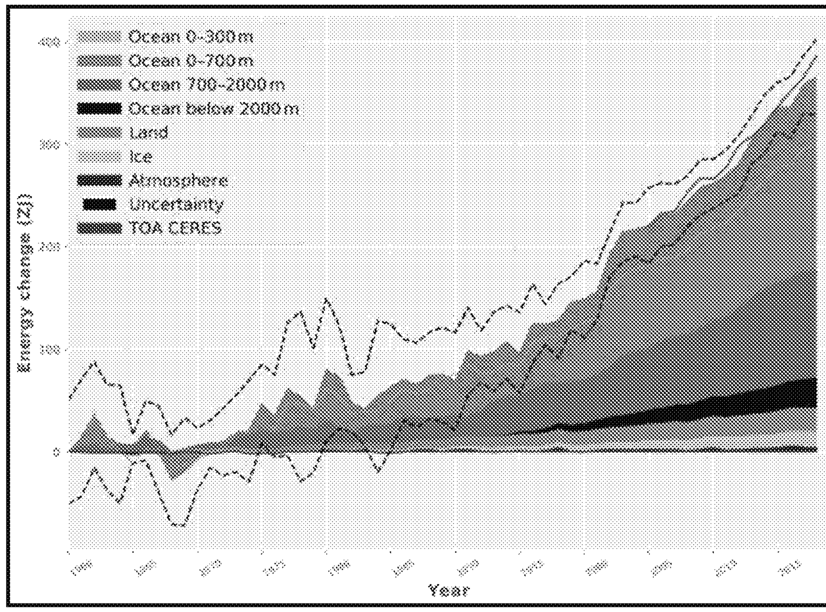

Figure 5 . Earth energy accumulation relative to 1960.

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[18] von Schuckmann, *Heat Stored in the Earth System*; Hansen, *Assessing "Dangerous Climate Change,"* at 1; IPCC, *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2013); L. Cheng et al., *How Fast are the Oceans Warming?* 363 Science 128 (2019) (as of 2019, about 93% of the energy balance accumulates in the ocean); NOAA, *What is Ocean Acidification?,* https://oceanservice.noaa.gov/facts/acidification.html.

[19] L. Cheng et al., *How Fast are the Oceans Warming?*, 363 Science 128 (2019).

[20] https://www.abc.net.au/news/2021-01-18/ocean-temperatures-reached-record-high-in-2020-study-finds/13062628; https://www.cambridgenetwork.co.uk/news/world-continued-warm-2020.

[21] T. P. Hughes et al., *Global Warming Impairs Stock-Recruitment Dynamics of Corals*, 568 Nature 387 (2019).

[22] K. Frieler et al., *Limiting Global Warming to 2 ℃ is Unlikely to Save Most Coral Reefs*, 3 Nature Climate Change 165 (2013); J. Veron et al; *The Coral Reef Crisis: The Critical Importance of <350ppm CO_2*, 58 Marine Pollution Bulletin 1428 (2009); T. P. Hughes et al., *Spatial and Temporal Patterns of Mass Bleaching of Corals in the Anthropocene*, 359 Science 80 (2018); T. P. Hughes et al., *Global Warming Impairs Stock–Recruitment Dynamics of Corals*, 568 Nature 387 (2019).

[23] Ove Hoegh-Guldberg et al., *Impacts of 1.5℃ Global Warming on Natural and Human Systems, in* Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, at 225-226 (2018); IPCC, *Summary for Policymakers, in* Global Warming of 1.5°C (2018).

U.S. Virgin Islands have been harmed by mass bleaching and coral diseases and could disappear by mid-century as a result of warming waters.[24] Scientists believe we can protect marine life and prevent massive bleaching and die-off of coral reefs only by rapidly returning CO_2 levels to below 350 ppm.[25]

No scientific institution, including the IPCC, has ever concluded that the Earth energy imbalance, which exists with >350 ppm, and 1.5-2°C warming would be safe for ocean life. According to Dr. Ove Hoegh-Guldberg, one of the world's leading experts on ocean warming and acidification, and a Coordinating Lead Author on the "The Ocean" chapter of the IPCC's Fifth Assessment Report and on the "Impacts of 1.5°C Global Warming on Natural and Human Systems" of the IPCC's Special Report on Global Warming of 1.5°C:

"Allowing a temperature rise of up to 2°C would seriously jeopardize ocean life, and the income and livelihoods of those who depend on healthy marine ecosystems. Indeed, the best science available suggests that coral dominated reefs will completely disappear if carbon dioxide concentrations exceed much more than today's concentrations. Failing to restrict further increases in atmospheric carbon dioxide will eliminate coral reefs as we know them and will deny future generations of children from enjoying these wonderful ecosystems."[26]

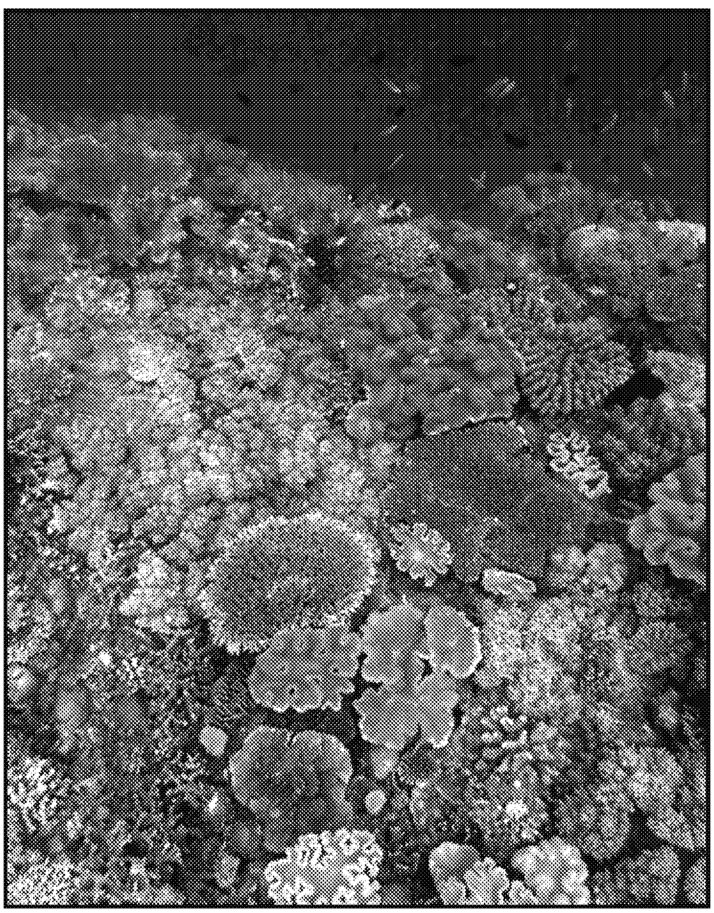

Figure 6: Healthy coral like this are already gravely threatened and will likely die with warming of 1.5°C.

Figure 7: Bleached coral from warmer ocean temperatures.

IPCC's Special Report on Global Warming of 1.5° states that "[w]arming of 1.5°C is not considered 'safe' for most nations, communities, ecosystems, and sectors and poses significant risks to natural and human systems as compared to current warming of 1°C (*high confidence*)."[27]

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[24] A.J. Pershing et al., *Oceans and Marine Resources, in* Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Vol. II (USGCRP, 2018).
[25] J. Veron et al., *The Coral Reef Crisis: The Critical Importance of <350 ppm CO_2*, 58 Marine Pollution Bulletin 1428 (2009).
[26] Ove Hoegh-Guldberg, *Declaration in Support of Petitioners, Foster v. Wash. Dep't of Ecology*, No. 14-2-25295-1 SEA (Wash. Super. Ct. Aug. 24, 2015).
[27] J. Roy et al., *Sustainable Development, Poverty Eradication and Reducing Inequalities, in* Global Warming of 1.5°C,

ADDITIONAL OBSERVATIONS ILLUSTRATE THE DANGERS OF INCREASED WARMING

In addition to the evidence discussed above which illustrates the necessity of ensuring that the atmospheric CO_2 concentration returns to no more than 350 ppm, based on present day observations about climate impacts occurring **now**, it is clear that the present level of 412 ppm and resulting heating of 1.1°C (as of 2020) is already causing significant climate impacts and additional warming will exacerbate these already dangerous impacts. Climate impacts that are already being experienced today include:

- Declining snowpack and rising temperatures are increasing the length and severity of drought conditions, especially in the western United States and Southwest, causing problems for agriculture users, forcing some people to relocate, and leading to water restrictions.[28]
- In the western United States, the wildfire season is now almost three months longer (87 days) than it was in the 1980s.[29] 10.3 million acres burned in 2020, well above the 2011-2020 average of 7.5 million acres.[30]
- Extreme weather events, such as intense rainfall events that cause flooding, are increasing in frequency and severity because a warmer atmosphere holds more moisture.[31] What are supposedly 1-in-1000-year rainfall events are now occurring with alarming frequency – in 2018 there were at least five such events.[32]
- Tropical storms and hurricanes are increasing in frequency and intensity, both in terms of rainfall and windspeed, as warmer oceans provide more energy for the storms (as seen with Hurricanes Harvey, Irma, and Maria in 2017)[33] (Figure 8).
- Terrestrial ecosystems are experiencing compositional and structural changes, with major adverse consequences for ecosystem services.[34]

Figure 8: Flooding in Port Arthur, Texas on August 13, 2018 after Hurricane Harvey.

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at 447 (2018).

[28] Steven W. Running, Declaration in Support of Plaintiffs, Juliana v. United States, No. 18-36082, Doc. 21-12 (9th Cir. Feb. 7, 2019).

[29] *Id.*; A. L. Westerling, *Increasing Western US Forest Wildfire Activity: Sensitivity to Changes in the Timing of Spring*, 371 Phil. Trans. R. Soc. B 20150178 (2016).

[30] Congressional Research Service, *Wildfire Statistics* (updated Jan. 4, 2021).

[31] Kevin E. Trenberth, Declaration in Support of Plaintiffs, Juliana v. United States, No. 18-36082, Doc. 21-3 (9th Cir. Feb. 7, 2019).

[32] F. Belles, *America's 'One-in-1,000-Year' Rainfall Events in 2018*, The Weather Channel (Sept. 27, 2018).

[33] Kevin E. Trenberth, Declaration in Support of Plaintiffs, Juliana v. United States, No. 18-36082, Doc. 21-3 (9th Cir. Feb. 7, 2019).

[34] C. Nolan et al., *Past and Future Global Transformation of Terrestrial Ecosystems Under Climate Change*, 361 Science

- Terrestrial, freshwater, and marine species are experiencing a significant decrease in population size and geographic range, with some going extinct and others are facing the very real prospect of extinction – the rapid rate of extinctions has been called the sixth mass extinction.[35]
- Human health and well-being are already being affected by heat waves, floods, droughts, and extreme events; infectious diseases; and quality of air, food, and water.[36] Doctors and leading medical institutions are calling climate change a "health emergency."[37] Children are uniquely vulnerable to climate change health effects due to their higher respiratory rate, lung growth and development, immature immune system, higher metabolic demands, and immature central nervous system.[38]
- In addition to physical harm, climate change is causing mental health impacts, ranging from stress to clinical disorders such as anxiety, depression, and suicidality, due to exposure to climate events, displacement, loss of income, chronic stress, and other impacts of climate change.[39]


Figure 9: Offutt Air Force Base was impacted by flood waters during flooding in Nebraska during spring 2019.

- As Congress has recognized, "climate change is a direct threat to the national security of the United States and is impacting stability in areas of the world both where the United States Armed Forces are operating today, and where strategic implications for future conflict exist."[40] Senior military leaders have called climate change "*the* most serious national security threat facing our Nation

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920 (2018).

[35] G. Ceballos et al., *Accelerated Modern Human–Induced Species Losses: Entering the Sixth Mass Extinction*, 1 Science Advances e1400253 (2015); Steven W. Running, Expert Report, Juliana v. United States, No. 6:15-cv-01517-TC, Doc. 264-1 (D. Or. June 28, 2018).

[36] K.L. Ebi et al., *Human Health, in* Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Vol. II (USGCRP, 2018).

[37] C.G. Solomon & R.C. LaRocque, *Climate Change – A Health Emergency*, 380 N. Engl. J. Med. 209 (2019).

[38] S. Pacheco, *Catastrophic Effects of Climate Change on Children's Health Start before Birth*, 130 Journal of Clinical Investigation 562 (2020); C. May et al., *Northwest, in* Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Vol. II (USGCRP, 2018); N. Watts et al., *The 2019 Report of The Lancet Countdown on Health and Climate Change: Ensuring that the Health of a Child Born Today is not Defined by a Changing Climate*, 394 The Lancet 1836 (2019); *Brief of Amici Curiae Public Health Experts, Public Health Organizations, and Doctors in Support of Plaintiffs*, No. 18-36082, Doc. 47 (9th Cir. Mar. 1, 2019).

[39] Lise Van Susteren, *Expert Report, Juliana v. United States*, No. 6:15-cv-01517-TC, Doc. 271-1 (D. Or. June 28, 2018). K.L. Ebi et al., *Human Health, in* Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Vol. II (USGCRP, 2018).

[40] *National Defense Authorization Act for Fiscal Year 2018*, Pub. L. No. 115-91, 131 Stat. 1358.

today,"[41] a conclusion similarly recognized by our Nation's intelligence community.[42] Climate change is increasing food and water shortages, pandemic disease, conflicts over refugees and resources, and destruction to homes, land, infrastructure, and military assets, directly threatening our military personnel and the "Department of Defense's ability to defend the Nation" (see Figure 9).[43]

- Climate change is already causing vast economic harm in the United States. Since 1980 the United States has experienced 285 climate and weather disasters that each caused damages in excess of $1 billion, for a total cost of $1.875 trillion.[44] In 2018 alone, Congress appropriated more than $130 billion for weather and climate related disasters.[45]

These already serious impacts will grow in severity and will impact increasingly large numbers of people and parts of the world if CO_2 concentrations continue to rise. If we want our children and grandchildren to have a safe planet to live on, full of health and biodiversity rather than chaos and conflict, we must follow the best scientific prescription to restore Earth's energy balance and avoid the destruction of our planet's atmosphere, climate, and oceans.

INTERNATIONAL POLITICAL TARGETS OF 1.5°C OR 2°C ARE NOT SCIENCE-BASED AND ARE NOT SAFE

International treaties require the stabilization of the climate system to avoid dangerous anthropogenic climate change. As described above, EEI and CO_2 concentrations should be the measurable scientific metrics, adopted as legal standards, for setting emission reduction and sequestration targets to stabilize our climate, avoid danger, and protect children and future generations. Temperature targets, set higher than today's already-too-hot planet, which would mean an even greater and more dangerous EEI and greater instability, are incompatible with fundamental human rights. International, politically-established temperature targets like 1.5°C or "well below" 2°C – which are commonly associated with long-term atmospheric CO_2 concentrations of 425 and 450 ppm, respectively – have not been and are not presently considered safe or scientifically-sound targets for present or future generations.

Legalizing heating of 1.5°C-2°C legalizes greater dangers than we have already witnessed. It is a death sentence for young people. In fact, Sir David King, former Special Envoy for Climate Change and Chief Scientific Advisor for the United Kingdom, elaborated on the importance of 350 ppm and limiting global heating to 1°C:

> *As a key negotiator for the United Kingdom government during discussions leading up to the Paris Agreement, I advocated that 1.5°C was an acceptable level of global warming. However, I was wrong. In 2020, our planet experienced an average of 1.1°C*

[41] Vice Admiral Lee Gunn, USN (Ret.), Declaration in Support of Plaintiffs, Juliana v. United States, No. 18-36082, Doc. 21-17 (9th Cir. Feb. 7, 2019) (emphasis in original); *see also* CNA Military Advisory Board, *National Security and the Accelerating Risks of Climate Change* (2014).
[42] National Intelligence Council, *Implications for US National Security of Anticipated Climate Change* (Sept. 2016).
[43] U.S. Dep't of Defense, *2014 Climate Change Adaptation Roadmap* (2014).
[44] NOAA, *Billion Dollar U.S. Weather/Climate Disasters 1980-2020* (2020), https://www.ncdc.noaa.gov/billions/events.pdf.
[45] U.S. House of Representatives Committee on the Budget, *The Budgetary Impact of Climate Change* 2 (Nov. 27, 2018).

> *of warming — much higher in some places like the Arctic -- and we experienced catastrophic weather events and climate-related disasters. These will only become more frequent, and more severe, as our emissions continue to rise. We cannot afford to negotiate what we now know is the safest level for stabilizing our climate systems: We must limit warming to less than 1.0°C as fast as possible. The 350 ppm pathways findings in studies by Jim Williams and Evolved Energy Research successfully demonstrate that the United States has clear pathways available to significantly reduce emissions, protecting the health and livelihood of their citizens while also boosting their national economies. This will crucially enable the USA to join leading nations in managing this severe challenge to humanity.*[46]

Importantly, the IPCC has never established nor endorsed a target of 1.5°C or 2°C warming as a limit below which the climate system will be stable and the energy balance restored. It is beyond the IPCC's declared mandate to endorse a particular threshold of warming as "safe" or "dangerous." As the IPCC makes clear, "each major IPCC assessment has examined the impacts of [a] multiplicity of temperature changes but has left [it to the] political processes to make decisions on which thresholds may be appropriate."[47]

Neither 1.5°C nor 2°C warming above pre-industrial levels has ever been considered "safe" from either a political or scientific point of view. The 2°C figure was originally adopted in the political arena "from a set of heuristics," and it has retained predominantly political character ever since.[48] The 2°C figure has recently been all-but-abandoned as a credible policy goal, in light of the findings in IPCC's 1.5°C Special Report, and the mounting evidence leading up to its publication, that 2°C would be catastrophic relative to lower, still-achievable levels of warming.[49]

On the other hand, the idea of a 1.5°C target was first raised by the Alliance of Small Island States (AOSIS) in the negotiations leading up to the ill-fated 2009 UNFCCC Conference of Parties in Copenhagen.[50] AOSIS, however, was explicitly advocating a *well below* 1.5°C and *well below* 350 ppm target, on the basis of the research of Dr. James Hansen and his colleagues.[51] Political compromise, including pressure from the fossil fuel industry, on this target then led to the adoption of a goal of "pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" in Article 2 of the Paris Agreement. Yet the 2018 IPCC Special Report on 1.5°C has made clear that allowing a temperature rise of 1.5°C:

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[46] Correspondence from Sir David King to Julia Olson (Jan. 2021) (notes on file with Julia Olson); The Do One Better! Podcast, Interview with Sir David King, https://www.lidji.org/sir-david-king.

[47] IPCC, *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report* 125 (Cambridge University Press, 2014).

[48] S. Randalls, *History of the 2°C Temperature Target*, 1 WIREs Climate Change 598, 603 (2010); C. Jaeger & J. Jaeger, *Three Views of Two Degrees*, 11 (Suppl 1) Reg. Environ. Change S15 (2011).

[49] IPCC, *Summary for Policymakers, in* Climate Change 2014: Impacts, Adaptation, and Vulnerability, 13-14 (2014); UNFCCC, *Report on the Structured Expert Dialogue on the 2013–2015 Review*, 18 (2015), http://unfccc.int/resource/docs/2015/sb/eng/inf01.pdf; Petra Tschakert, *1.5°C or 2°C: A Conduit's View from the Science-Policy Interface at COP20 in Lima, Peru*, 2 Climate Change Responses 8 (2015); IPCC, *Global Warming of 1.5°C* (2018).

[50] *See* R. Webster, *A Brief History of the 1.5C Target*. Climate Change News (Dec. 10, 2015), http://www.climatechangenews.com/2015/12/10/a-brief-history-of-the-1-5c-target/.

[51] *Submission from Grenada on behalf of AOISIS to the Ad Hoc Working Group on Further Commitments for Annex I Parties Under the Kyoto Protocol*, U.N. Doc. FCCC/KP/AWG/2009/MISC.1/Add.1 (25 March 2009), https://unfccc.int/sites/default/files/resource/docs/2009/awg7/eng/misc01a01.pdf, citing James Hansen et al. *Target Atmospheric CO_2: Where Should Humanity Aim?* 2 The Open Atmospheric Science Journal 217 (2008).

> is **not considered 'safe'** for most nations, communities, ecosystems, and sectors and poses significant risks to natural and human systems as compared to current warming of 1°C (*high confidence*).[52]

Dr. James Hansen warns that "distinctions between pathways aimed at ~1°C and 2°C warming are much greater and more fundamental than the numbers 1°C and 2°C themselves might suggest. These fundamental distinctions make scenarios with 2°C or more global warming far more dangerous; so dangerous, we [James Hansen et al.] suggest, that aiming for the 2°C pathway would be foolhardy."[53] This target is at best the equivalent of "flip[ping] a coin in the hopes that future generations are not left with few choices beyond mere survival. This is not risk management, it is recklessness and we must do better."[54]

Tellingly, more than 80 eminent scientists from over 50 different institutions have been co-authors on publications in peer-reviewed journals finding that the maximum level of atmospheric CO_2 consistent with restoring the EEI, protecting humanity and other species is 350 ppm, and no one, including the IPCC, has published any scientific evidence to counter that 350 ppm is the maximum safe concentration of CO_2.[55]

A 1.5° OR 2°C TARGET RISKS LOCKING-IN DANGEROUS FEEDBACKS

The longer the length of time atmospheric CO_2 concentrations remain at dangerous levels (i.e., above 350 ppm) and there is an Earth energy imbalance, the risk of triggering, and locking-in, dangerous warming-driven feedback loops increases. The 1.5°C or 2°C target (linked to 425-450 ppm) reduces the likelihood that the biosphere will be able to sequester CO_2 due to carbon cycle feedbacks and shifting climate zones.[56] As Earth surface temperatures increase, forests burn and soils warm, releasing their carbon. These natural carbon "sinks" become carbon "sources" and a portion of the natural carbon sequestration necessary to drawdown excess CO_2 simply disappear. Another dangerous feedback includes the release of methane, a potent greenhouse gas, as the global tundra thaws.[57] These feedbacks might show little change in the short-term, but can hit a point of no return, even at a 1.5°C or 2°C temperature increase, which will trigger accelerated heating and sudden *and irreversible* catastrophic impacts. Moreover, an emission reduction target aimed at 2°C would "yield

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[52] J. Roy et al., *Sustainable Development, Poverty Eradication and Reducing Inequalities, in* Global Warming of 1.5°C, at 447 (2018) (emphasis added).
[53] Hansen, *Assessing "Dangerous Climate Change*," at 15.
[54] Matt Vespa, *Why 350? Climate Policy Must Aim to Stabilize Greenhouse Gases at the Level Necessary to Minimize the Risk of Catastrophic Outcomes*, 36 Ecology Law Currents 185, 186 (2009).
[55] James Hansen, et al., *Target Atmospheric CO_2: Where Should Humanity Aim?* 2 The Open Atmospheric Science Journal 217 (2008); Hansen, *Assessing "Dangerous Climate Change"*; Hansen, *Ice Melt, Sea Level Rise and Superstorms*; James Hansen, et al., *Young People's Burden: Requirement of Negative CO_2 Emissions*, 8 Earth Syst. Dynamics 577 (2017); J. Veron, et al., *The Coral Reef Crisis: The Critical Importance of <350 ppm CO_2* 58 Marine Pollution Bulletin 1428 (2009); K. Frieler, et al., *Limiting Global Warming to 2 ℃ is Unlikely to Save Most Coral Reefs* 3 Nature Climate Change 165 (2013); von Schuckmann, *Heat Stored in the Earth System*; Communication from James Hansen, Karina von Shuckmann to Julia Olson (2021) (notes on file with Julia Olson).
[56] Hansen, *Assessing "Dangerous Climate Change,"* at 15, 20.
[57] *Id.*

a larger eventual warming because of slow feedbacks, probably at least 3°C."[58] Once a temperature increase of 2°C is reached, there will already be "additional climate change 'in the pipeline' even without further change of atmospheric composition."[59]

THE BEST AVAILABLE SCIENCE REQUIRES US TO REDUCE CO_2 LEVELS TO <350 PPM BY 2100

There are two steps to reducing CO_2 levels to <350 ppm by the end of the century: 1) reducing CO_2 emissions; and separately 2) sequestering excess CO_2 already in the atmosphere (carbon drawdown). Carbon dioxide emission reductions of approximately 80% by 2030 and close to 100% by 2050 (in addition to the requisite CO_2 sequestration) are necessary to be on track to an atmospheric CO_2 concentration to 350 ppm, restoring energy balance, and keeping long-term warming to below 1°C above preindustrial temperatures. Politically-motivated emission reduction targets that seek to reduce CO_2 emissions by only 80% by 2050 are consistent with an atmospheric CO_2 concentration of 450 ppm and long-term warming of 2°C, which, as described above, would result in catastrophic and irreversible impacts for the climate system and oceans.

IT IS TECHNOLOGICALLY AND ECONOMICALLY FEASIBLE TO REDUCE EMISSIONS IN LINE WITH 350 PPM BY 2100

Importantly, it is economically and technologically feasible to transition the entire U.S. energy system to a zero-CO_2 energy system by 2050 and to drawdown the excess CO_2 in the atmosphere through reforestation and carbon sequestration in soils.[60]

Deep Decarbonization Pathways Project and Evolved Energy Research recently completed research and very sophisticated modeling describing a nearly complete phase out of fossil fuels in the U.S. by 2050.[61] They describe six different technologically feasible pathways to drastically, and quickly, cut our reliance on fossil fuels and achieve the requisite level of emissions reductions in the U.S. while meeting our nation's forecasted energy needs. All of the 350 ppm pathways rely on four pillars of action: a) investment in energy efficiency; b) electrification of everything that can be electrified; c) shifting to very low-carbon and primarily renewable electricity generation; and d) carbon dioxide capture as fossil fuels are phased out. The six scenarios are used to evaluate the ability to meet the targets even absent one key technology. For example, one scenario describes a route to 350 ppm absent construction of new nuclear facilities; another illustrates getting to 350 ppm with extremely limited biomass technology; still another describes a way to 350 ppm without any carbon capture and storage. Even absent a key technology, each of these six routes are viable and cost effective.

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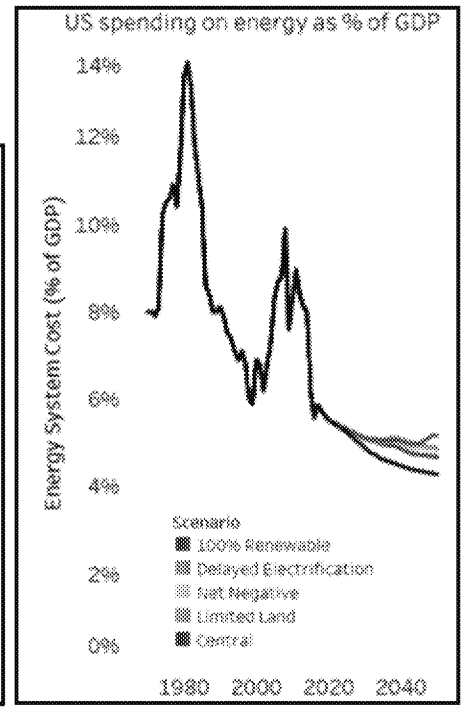
[58] *Id.* at 15.
[59] *Id.* at 19.
[60] *See* Mark Z. Jacobson et al., *100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for the 50 United States,* 8 Energy & Envtl. Sci. 2093 (2015) (for plans on how the United States and over 100 other countries can transition to a 100% renewable energy economy see www.thesolutionsproject.org); *see also* Arjun Makhijani, *Carbon-Free, Nuclear-Free: A Roadmap for U.S. Energy Policy* (2007); B. Haley et al., *350 ppm Pathways for the United States* (2019); James Williams et al., *Carbon-Neutral Pathways for the United States*, 2 AGU Advances e2020AV000284 (2021).
[61] B. Haley et al., *350 ppm Pathways for the United States* (2019).

A related 2021 study concludes that emissions reductions consistent with a 350 ppm trajectory by 2100 can be done at low net cost, substantially lower than estimates for less ambitious 80% by 2050 scenarios a few years ago due to recent declines in solar, wind, and vehicle battery prices.[62] The cost would be well below the 9.5% of GDP spent on the energy system in 2009 (not to mention well below the harm to the economy caused by climate change). (Figure 10)[63] Once the transition is complete, the cost of energy will remain low and stable because we will no longer be dependent on volatile global fossil fuel markets for our energy supplies. As Nobel Laureate Economist Dr. Joseph Stiglitz has stated: "[t]he benefits of making choices today that limit the economic costs of climate change far outweigh any economic costs associated with limiting our use of fossil fuels."[64]



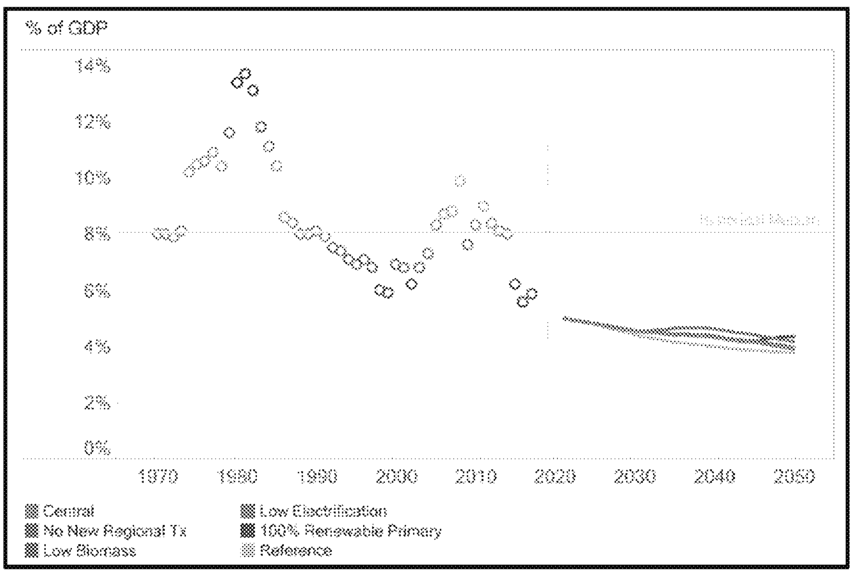


Figure 10: Historic and projected costs of energy in the U.S. as percentage of GDP.

Other experts have already prepared plans for all 50 U.S. states as well as for over 139 countries that demonstrate the technological and economic feasibility of transitioning off of fossil fuels toward 100% of energy, for all energy sectors, from clean and renewable energy sources: wind, water, and sunlight by 2050 (with 80% reductions in fossil fuels by 2030).[65]

Products already exist that enable new construction or retrofits that result in zero greenhouse gas buildings. We have the technology to meet all electricity needs with zero-emission electric generation. We know how to achieve zero-emission transportation, including aviation. These actions result in other benefits, such as improved health, job creation, and savings on energy costs.

The amount of natural carbon sequestration required is also proven to be feasible. Researchers have evaluated the potential to drawdown excess carbon dioxide in the atmosphere by increasing the carbon

[62] James Williams et al., *Carbon-Neutral Pathways for the United States*, 2 AGU Advances e2020AV000284 (2021).
[63] *Id.*, Ben Haley et al., *350 ppm Pathways for Florida, Technical Supplement* (2020).
[64] Joseph E. Stiglitz, Ph.D., Declaration in Support of Plaintiffs, Juliana v. United States, No. 18-36082, Doc. 21-14 (9th Cir. Feb. 7, 2019).
[65] Mark Z. Jacobson et al., *100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for the 50 United States,* 8 Energy & Envtl. Sci. 2093 (2015). For a graphic depicting the overview of the plan for the United States see: https://thesolutionsproject.org/why-clean-energy/#/map/countries/location/USA.

stored in forests, soils, and wetlands, and have found significant potential for these natural systems to support a return to 350 ppm by the end of the century.[66] We know the agricultural, rangeland, wetland, and forest management practices that decrease greenhouse gas emissions and increase sequestration.

There is no scientific, technological, or economic reason to *not* adopt a <350 ppm and 1°C by 2100 target. There are abundant reasons for doing so, not the least of which is to do our best through human laws to respect the laws of nature and create a safe and healthy world for children and future generations.

A NOTE ON "NET ZERO"

The politically popular concept of "net zero" allows governments to zero out a percentage of ongoing fossil fuel emissions by counting them as "sequestered" through removal processes, such as biogenic or natural sequestration in carbon sinks, leaving a smaller amount of source "net emissions" to be reduced. However, in order to align emissions and sequestration with a <350 ppm standard, carbon removed through natural sequestration in sinks must be used to draw down the excess CO_2 already in the atmosphere from cumulative historic emissions, not to provide a negative credit or offset for ongoing emissions. Emissions and sequestration must be accounted and inventoried separately with separate standards for each category.[67] A "net zero" emissions target is a shell game with little accountability, detached from a precise standard for protection of fundamental rights and restoration of Earth's energy balance.

[66] Benson W. Griscom et al., *Natural Climate Solutions,* 114 Proceedings of the National Academies of Sciences 11645 (2017); Joseph E. Fargione et al., *Natural Climate Solutions for the United States,* 4 Science Advances eaat1869 (2018).
[67] D. McLaren et al., *Beyond "Net-Zero": A Case for Separate Targets for Emissions Reduction and Negative Emissions*, Front. Clim. (2019).

Attachment 2

EXECUTIVE SUMMARY

350 PPM PATHWAYS
FOR THE UNITED STATES

May 8, 2019

EVOLVED ENERGY RESEARCH

Prepared by

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DEEP DECARBONIZATION PATHWAYS PROJECT

Executive Summary

This report describes the changes in the U.S. energy system required to reduce carbon dioxide (CO_2) emissions to a level consistent with returning atmospheric concentrations to 350 parts per million (350 ppm) in 2100, achieving net negative CO_2 emissions by mid-century, and limiting end-of-century global warming to 1°C above pre-industrial levels. The main finding is that 350 ppm pathways that meet all current and forecast U.S. energy needs are technically feasible using existing technology, and that multiple alternative pathways can meet these objectives in the case of limits on some key decarbonization strategies. These pathways are economically viable, with a net increase in the cost of supplying and using energy equivalent to about 2% of GDP, up to a maximum of 3% of GDP, relative to the cost of a business-as-usual baseline. These figures are for energy costs only and do not count the economic benefits of avoided climate change and other energy-related environmental and public health impacts, which have been described elsewhere.[1]

This study builds on previous work, *Pathways to Deep Decarbonization in the United States* (2014) and *Policy Implications of Deep Decarbonization in the United States* (2015), which examined the requirements for reducing GHG emissions by 80% below 1990 levels by 2050 ("80 x 50").[2] These studies found that an 80% reduction by mid-century is technically feasible and economically affordable, and attainable using different technological approaches. The main requirement of the transition is the construction of a low carbon infrastructure characterized by high energy efficiency, low-carbon electricity, and replacement of fossil fuel combustion with decarbonized electricity and other fuels, along with the policies needed to achieve this transformation. The findings of the present study are similar but reflect both a more stringent emissions limit and the consequences of five intervening years without aggressive emissions reductions in the U.S. or globally.

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[1] See e.g. *Risky Business: The Bottom Line on Climate Change,* available at https://riskybusiness.org/

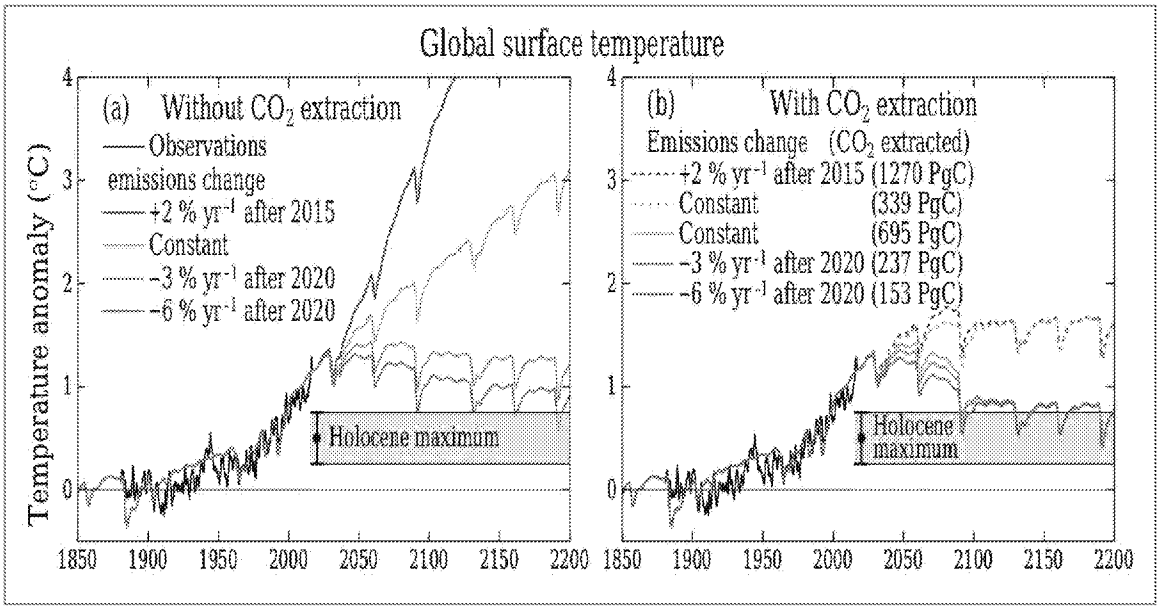
[2] Available at http://usddpp.org/.

The 80 x 50 analysis was developed in concert with similar studies for other high-emitting countries by the country research teams of the Deep Decarbonization Pathways Project, with an agreed objective of limiting global warming to 2°C above pre-industrial levels.[3] However, new studies of climate change have led to a growing consensus that even a 2°C increase may be too high to avoid dangerous impacts. Some scientists assert that staying well below 1.5°C, with a return to 1°C or less by the end of the century, will be necessary to avoid irreversible feedbacks to the climate system.[4] A recent report by the IPCC indicates that keeping warming below 1.5°C will likely require reaching net-zero emissions of CO_2 globally by mid-century or earlier.[5] A number of jurisdictions around the world have accordingly announced more aggressive emissions targets, for example California's recent executive order calling for the state to achieve carbon neutrality by 2045 and net negative emissions thereafter.[6]

In this study we have modeled the pathways – the sequence of technology and infrastructure changes – consistent with net negative CO_2 emissions before mid-century and with keeping peak warming below 1.5°C. We model these pathways for the U.S. for each year from 2020 to 2050, following a global emissions trajectory that would return atmospheric CO_2 to 350 ppm by 2100, causing warming to peak well below 1.5°C and not exceed 1.0°C by century's end.[7] The cases modeled are a 6% per year and a 12% per year reduction in net fossil fuel CO_2 emissions after 2020. These equate to a cumulative emissions limit for the U.S. during the 2020 to 2050 period of 74 billion metric tons of CO_2 in the 6% case and 47 billion metric tons in the 12% case. (For comparison, current U.S. CO_2 emissions are about 5 billion metric tons per year.) The emissions in both cases must be accompanied by increased extraction of CO_2 from the atmosphere using land-based negative emissions technologies ("land NETs"), such as reforestation, with greater extraction required in the 6% case.

[3] Available at http://deepdecarbonization.org/countries/.
[4] James Hansen, et al. (2017) "Young people's burden: requirement of negative CO2 emissions," *Earth System Dynamics*, https://www.earth-syst-dynam.net/8/577/2017/esd-8-577-2017.html.
[5] Available at https://www.ipcc.ch/sr15/.
[6] Available at https://www.gov.ca.gov/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf.
[7] Hansen et al. (2017).

Figure ES1 Global surface temperature and CO2 emissions trajectories. Hansen et al, 2017.



We studied six different scenarios: five that follow the 6% per year reduction path and one that follows the 12% path. All reach net negative CO_2 by mid-century while providing the same energy services for daily life and industrial production as the *Annual Energy Outlook (AEO)*, the Department of Energy's long-term forecast. The scenarios explore the effects of limits on key decarbonization strategies: bioenergy, nuclear power, electrification, land NETs, and technological negative emissions technologies ("tech NETs"), such as carbon capture and storage (CCS) and direct air capture (DAC).

Table ES1. Scenarios developed in this study

Scenario	Average annual rate of CO_2 emission reduction	2020-2050 maximum cumulative fossil fuel CO_2 (million metric tons)	Year 2050 maximum net fossil fuel CO_2 (million metric tons)	Year 2050 maximum net CO_2 with 50% increase in land sink (million metric tons)
Base	6%	73,900	830	-250
Low Biomass	6%	73,900	830	-250
Low Electrification	6%	73,900	830	-250
No New Nuclear	6%	73,900	830	-250
No Tech NETS	6%	73,900	830	-250
Low Land NETS	12%	57,000	-200	-450

The scenarios were modeled using two new analysis tools developed for this purpose, EnergyPATHWAYS and RIO. As extensively described in the Appendix, these are sophisticated models with a high level of sectoral, temporal, and geographic detail, which ensure that the scenarios account for such things as the inertia of infrastructure stocks and the hour-to-hour dynamics of the electricity system, separately in each of fourteen electric grid regions of the U.S. The changes in energy mix, emissions, and costs for the six scenarios were calculated relative to a high-carbon baseline also drawn from the *AEO*.

Relative to 80 x 50 trajectories, a 350 ppm trajectory that achieves net negative CO_2 by mid-century requires more rapid decarbonization of energy plus more rapid removal of CO_2 from the atmosphere. For this analysis, an enhanced land sink 50% larger than the current annual sink of approximately 700 million metric tons was assumed.[8] This would require additional sequestration of 25-30 billion metric tons of CO_2 from 2020 to 2100. The present study does not address the cost or technical feasibility of this assumption but stipulates it as a plausible value for calculating an overall CO_2 budget, based on consideration of the scientific literature in this area.[9]

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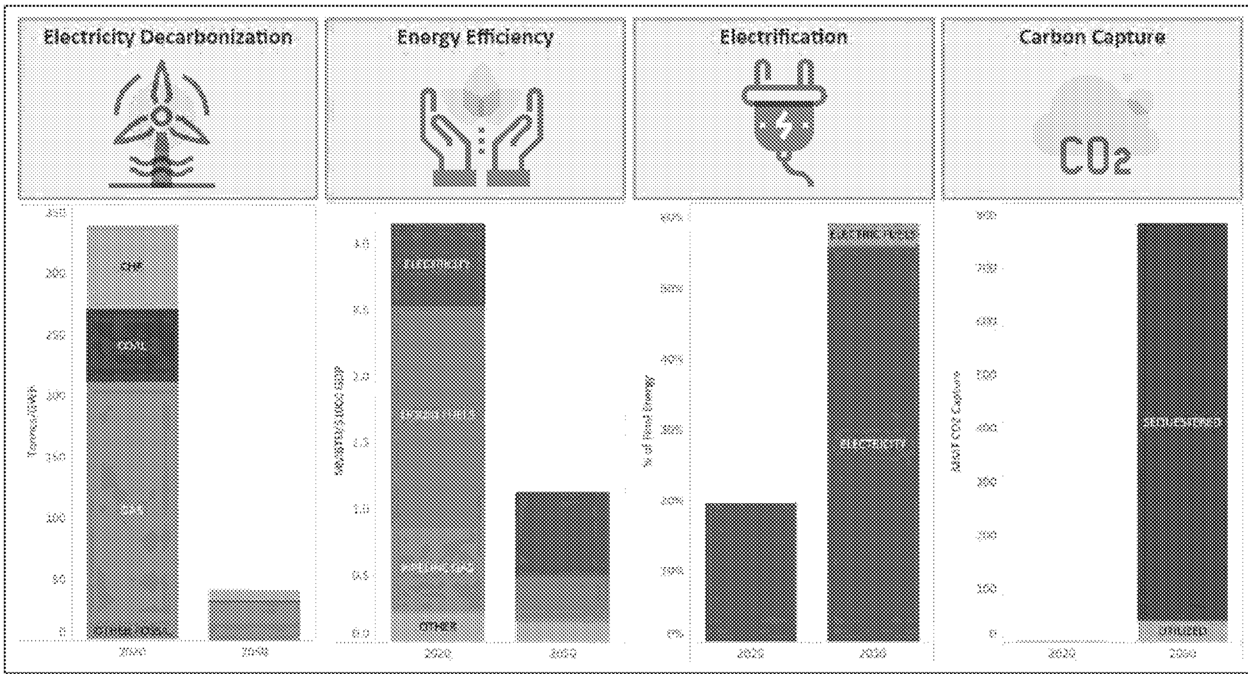
[8] U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016,* available at https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016

[9] Griscom, Bronson W., et al. (2017) "Natural climate solutions." *Proceedings of the National Academy of Sciences* 114.44 (2017): 11645-11650; Fargione, Joseph E., et al. (2018) "Natural climate solutions for the United States." *Science Advances* 4.11: eaat1869.

Figure ES2 Four pillars of deep decarbonization - Base case



Energy decarbonization rests on the four principal strategies ("four pillars") shown in Figure ES2: (1) electricity decarbonization, the reduction in emissions intensity of electricity generation by about 90% below today's level by 2050; (2) energy efficiency, the reduction in energy required to provide energy services such as heating and transportation, by about 60% below today's level; (3) electrification, converting end-uses like transportation and heating from fossils fuels to low-carbon electricity, so that electricity triples its share from 20% of current end uses to 60% in 2050; and (4) carbon capture, the capture of otherwise CO_2 that would otherwise be emitted from power plants and industrial facilities, plus direct air capture, rising from nearly zero today to as much as 800 million metric tons in 2050 in some scenarios. The captured carbon may be sequestered or may be utilized in making synthetic renewable fuels.

Achieving this transformation by mid-century requires an aggressive deployment of low-carbon technologies. Key actions include retiring all existing coal power generation, approximately doubling electricity generation primarily with solar and wind power and electrifying virtually all passenger vehicles and natural gas uses in buildings. It also includes creating new types of infrastructure, namely large-scale industrial facilities for carbon capture and storage, direct air capture of CO_2, the production of gaseous and liquid biofuels with zero net lifecycle CO_2, and the production of hydrogen from water electrolysis using excess renewable electricity. The scale of the infrastructure buildout by region is indicated in Figure ES3.

Figure ES3 Regional infrastructure requirements (Low Land NETS scenario)

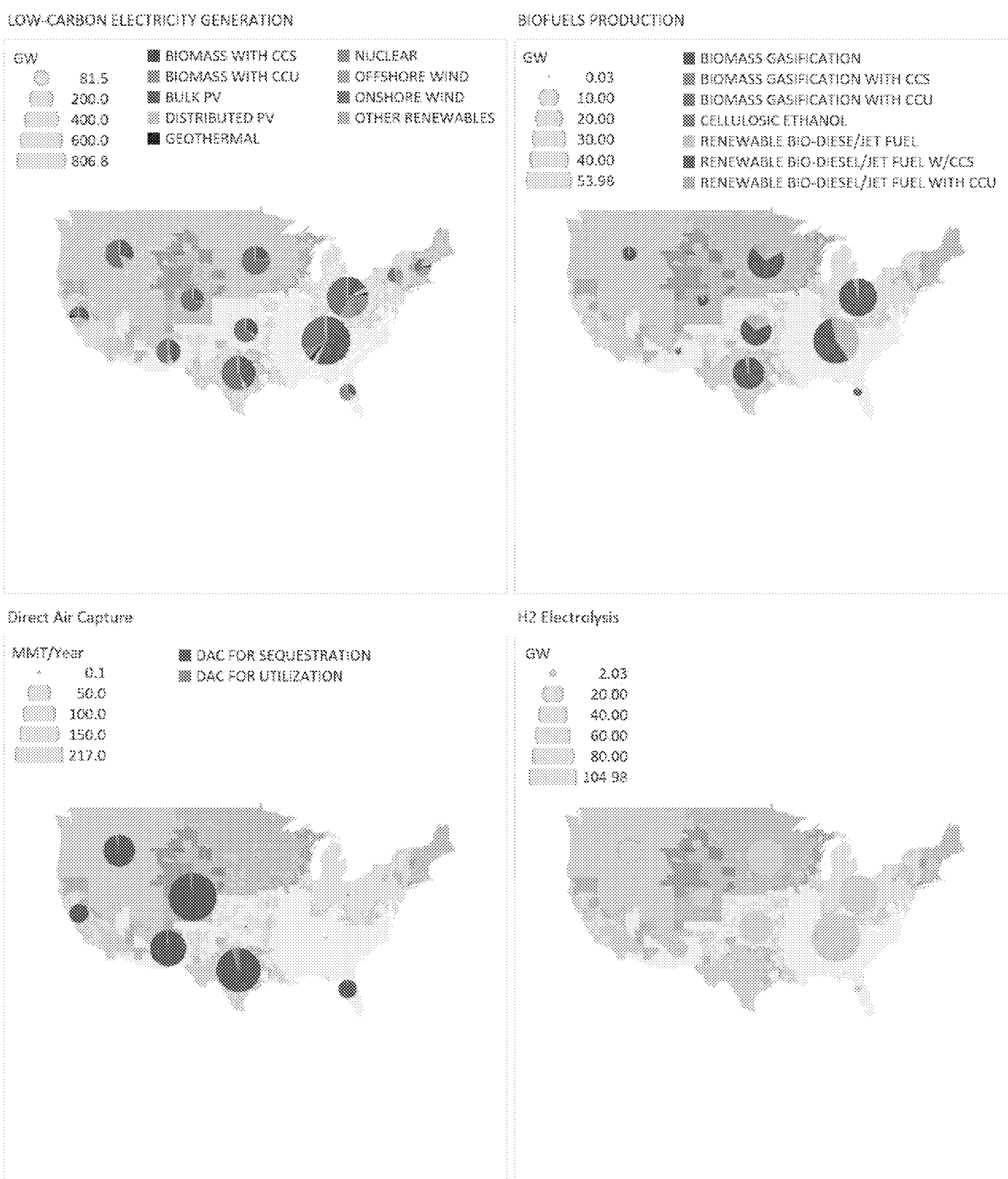


Figure ES4 shows that all scenarios achieve the steep reductions in net fossil fuel CO_2 emissions to reach net negative emissions by the 2040s, given a 50% increase in the land sink, including five that are limited in one key area. This indicates that the feasibility of reaching the emissions goals is robust due to the ability to substitute strategies. At same time, the more limited scenarios are, the more difficult and/or costly they are relative to the base case with all options available. Severe limits in two or more areas were not studied here but would make the emissions goals more difficult to achieve in the mid-century time frame.

Figure ES4 2020-2050 CO_2 emissions for the scenarios in this study

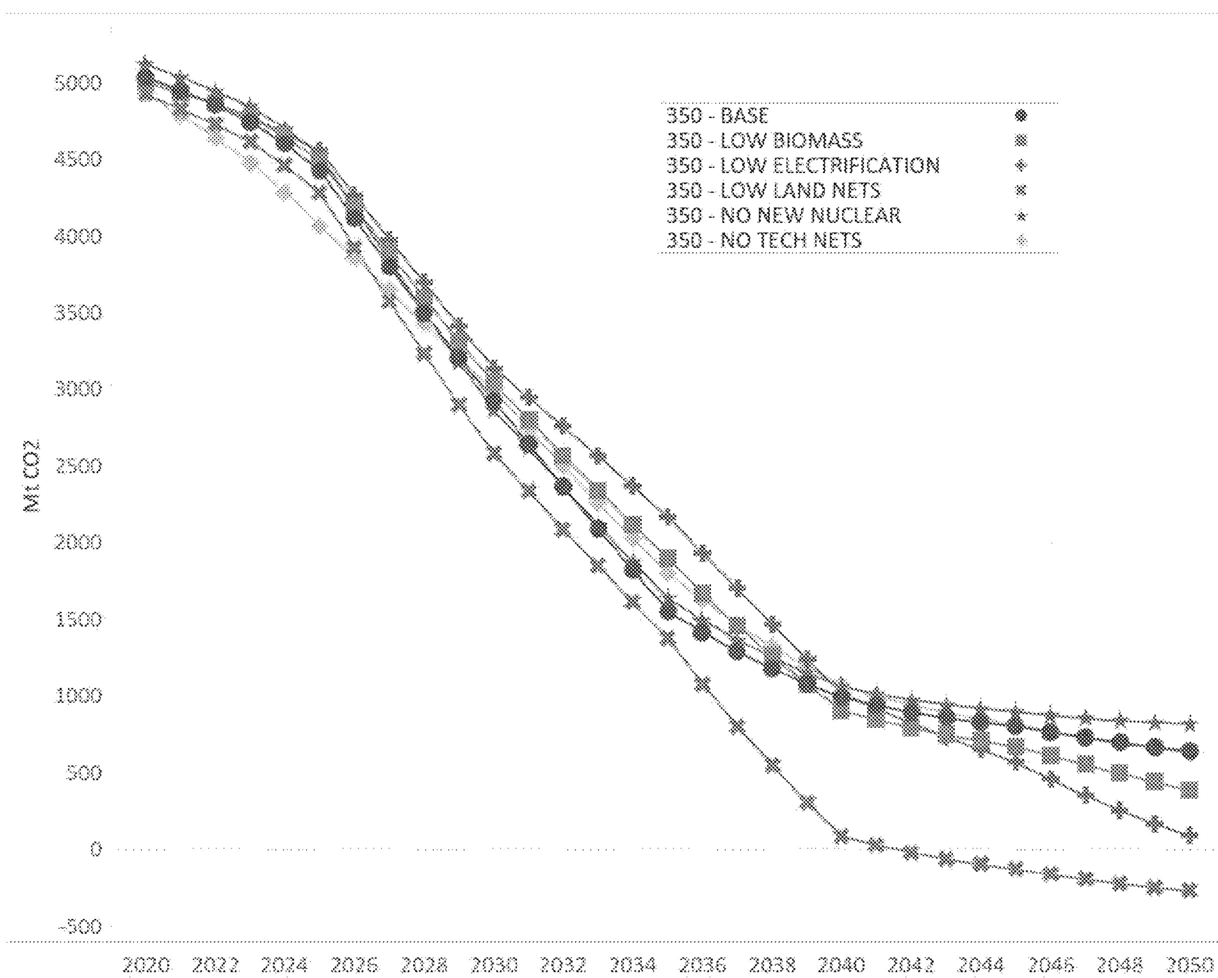
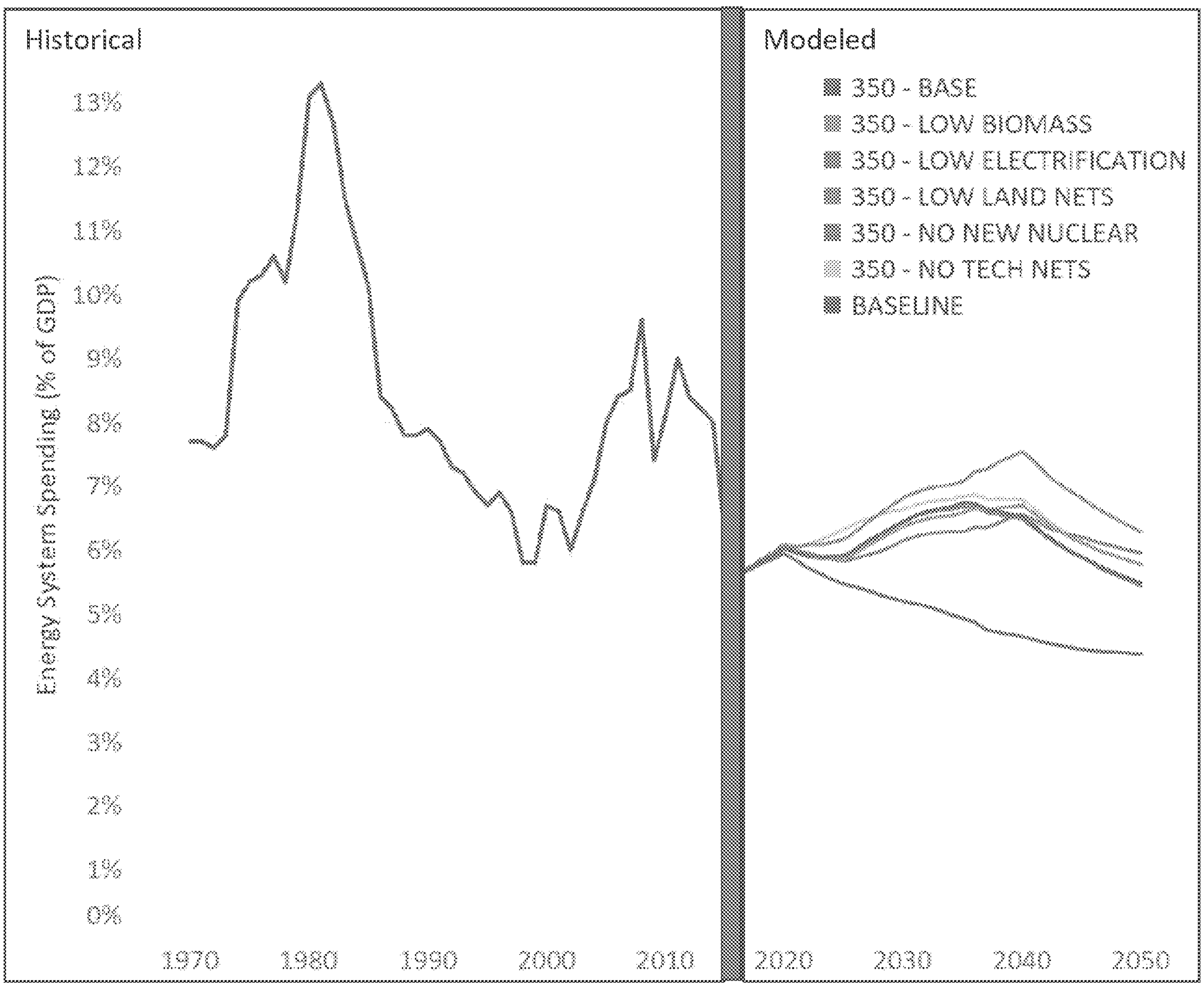


Figure ES5 shows U.S. energy system costs as a share of GDP for the baseline case and six 350 ppm scenarios in comparison to historical energy system costs. While the 350 ppm scenarios have a net cost of 2-3% of GDP more than the business as usual baseline, these costs are not out of line with historical energy costs in the U.S. The highest cost case is the Low Land NETs scenario, which requires a 12% per year reduction in net fossil fuel CO_2 emissions. By comparison, the 6% per year reduction cases are more closely clustered. The lowest increase is the Base scenario, which incorporates all the key decarbonization strategies. These costs do not include any potential economic benefits of avoided climate change or pollution, which could equal or exceed the net costs shown here.

Figure ES5. Total energy system costs as percentage of GDP, modeled (R.) and historical (L.)



A key finding of this study is the potentially important future role of "the circular carbon economy." This refers to the economic complementarity of hydrogen production, direct air capture of CO_2, and fuel synthesis, in combination with an electricity system with very high levels of intermittent renewable generation. If these facilities operate flexibly to take advantage of periods of excess generation, the production of hydrogen and CO_2 feedstocks can provide an economic use for otherwise curtailed energy that is difficult to utilize with electric energy storage technologies of limited duration. These hydrogen and CO_2 feedstocks can be combined as alternatives for gaseous and liquid fuel end-uses that are difficult to electrify directly like freight applications and air travel. While the CO_2 is eventually emitted to the atmosphere, the overall process is carbon neutral as it was extracted from the air and not emitted from fossil reserves. A related finding of this work is that bioenergy with carbon capture and storage (BECCS) for power plants appears uneconomic, while BECCS for bio-refineries appears highly economic and can be used as an alternative source of CO_2 feedstocks in a low-carbon economy.

There are several areas outside the scope of this study that are important to provide a full picture of a low greenhouse gas transition. One important area is better understanding of the potential and cost of land-based NETs, both globally and in the U.S. Another is the potential and cost of reductions in non-CO_2 climate pollutants such as methane, nitrous oxide, and black carbon. Finally, there is the question of the prospects for significant reductions in energy service demand, due to lifestyle choices such as bicycling over cars, structural changes such as increased transit and use of ride-sharing, or the development of less-energy intensive industry, perhaps based on new types of materials.

"Key Actions by Decade" below provides a blueprint for the physical transformation of the energy system. From a policy perspective, this provides a list of the things that policy needs to accomplish, for example the deployment of large amounts of low carbon generation, rapid electrification of vehicles, buildings, and industry, and building extensive carbon capture, biofuel, hydrogen, and synthetic fuel synthesis capacity.

Some of the policy challenges that must be managed include: land use tradeoffs related to carbon storage in ecosystems and siting of low carbon generation and transmission; electricity market designs that maintain natural gas generation capacity for reliability while running it very infrequently; electricity market designs that reward demand side flexibility in high-renewables electricity system and encourage the development of complementary carbon capture and fuel synthesis industries; coordination of planning and policy across sectors that previously had little interaction but will require much more in a low carbon future, such as transportation and electricity; coordination of planning and policy across jurisdictions, both vertically from local to state to federal levels, and horizontally across neighbors and trading partners at the same level;

mobilizing investment for a rapid low carbon transition, while ensuring that new investments in long-lived infrastructure are made with full awareness of what they imply for long-term carbon commitment; and investing in ongoing modeling, analysis, and data collection that informs both public and private decision-making. These topics are discussed in more detail in *Policy Implications of Deep Decarbonization in the United States.*

Key Actions by Decade

This study identifies key actions that are required in each decade from now to mid-century in order to achieve net negative CO_2 emissions by mid-century, at least cost, while delivering the energy services projected in the *Annual Energy Outlook*. Such a list inherently relies on current knowledge and forecasts of unknowable future costs, capabilities, and events, yet a long-term blueprint remains essential because of the long lifetimes of infrastructure in the energy system and the carbon consequences of investment decisions made today. As events unfold, technology improves, energy service projections change, and understanding of climate science evolves, energy system analysis and blueprints of this type must be frequently updated.

2020s

- Begin large-scale electrification in transportation and buildings
- Switch from coal to gas in electricity system dispatch
- Ramp up construction of renewable generation and reinforce transmission
- Allow new natural gas power plants to be built to replace retiring plants
- Start electricity market reforms to prepare for a changing load and resource mix
- Maintain existing nuclear fleet
- Pilot new technologies that will need to be deployed at scale after 2030
- Stop developing new infrastructure to transport fossil fuels
- Begin building carbon capture for large industrial facilities

2030s

- Maximum build-out of renewable generation
- Attain near 100% sales share for key electrified technologies (e.g. EVs)
- Begin large-scale production of bio-diesel and bio-jet fuel
- Large scale carbon capture on industrial facilities
- Build out of electrical energy storage
- Deploy fossil power plants capable of 100% carbon capture if they exist

Maintain existing nuclear fleet

2040s

- Complete electrification process for key technologies, achieve 100% stock penetration
- Deploy circular carbon economy using DAC and hydrogen to produce synthetic fuels
- Use synthetic fuel production to balance and expand renewable generation
- Replace nuclear at the end of existing plant lifetime with new generation technologies
- Fully deploy biofuel production with carbon capture

Attachment 3

350 PPM PATHWAYS FOR FLORIDA

October 6, 2020

EVOLVED ENERGY RESEARCH

350 PPM Pathways for Florida

Prepared by

Ben Haley, Gabe Kwok, and Ryan Jones

Evolved Energy Research

October 6, 2020

Executive Summary

This study evaluates multiple scenarios to radically reduce the greenhouse gas emissions that result from Florida's energy system, and can serve as a tool to inform statewide energy system decisions.

We detail five technically and economically feasible pathways to reduce carbon dioxide emissions and remain within a small enough "carbon budget" to enable a return to 350 parts per million of carbon dioxide in the atmosphere by 2100, a level identified by scientists as a safe limit necessary to preserve a stable climate. These scenarios limit emissions while providing the same energy services for daily life and industrial production as the Department of Energy's long-term forecast.

This study builds upon the research conducted by Evolved Energy Research and the Sustainability Development Solutions Network (SDSN) and published on May 8, 2019, titled *350 PPM Pathways for the United States.*

Scenarios

This study evaluates five energy decarbonization[1] scenarios for the energy system of Florida:

Central: The least constrained scenario, this uses all options to decarbonize the energy system.

Low Biomass: This scenario reduces the development of new biomass feedstocks[2] by 50%.

Low Electrification: This scenario assesses the impact of a delayed adoption of electric vehicles and heat pumps.

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[1] "Decarbonization" is the process of removing sources of carbon dioxide (and other greenhouse gases) from a system – in this case, removing fossil fuel emissions from Florida's energy system.

[2] Biomass feedstocks are plant-based and animal-based sources of fuel, like trees, grasses, or animal fats, for example.

100% Renewable Primary: This scenario describes an energy system based solely on biomass, wind, solar, hydro, and geothermal sources by 2050.

No New Regional Transmission (TX): This scenario limits the development of new electricity transmission lines between regions within the U.S.

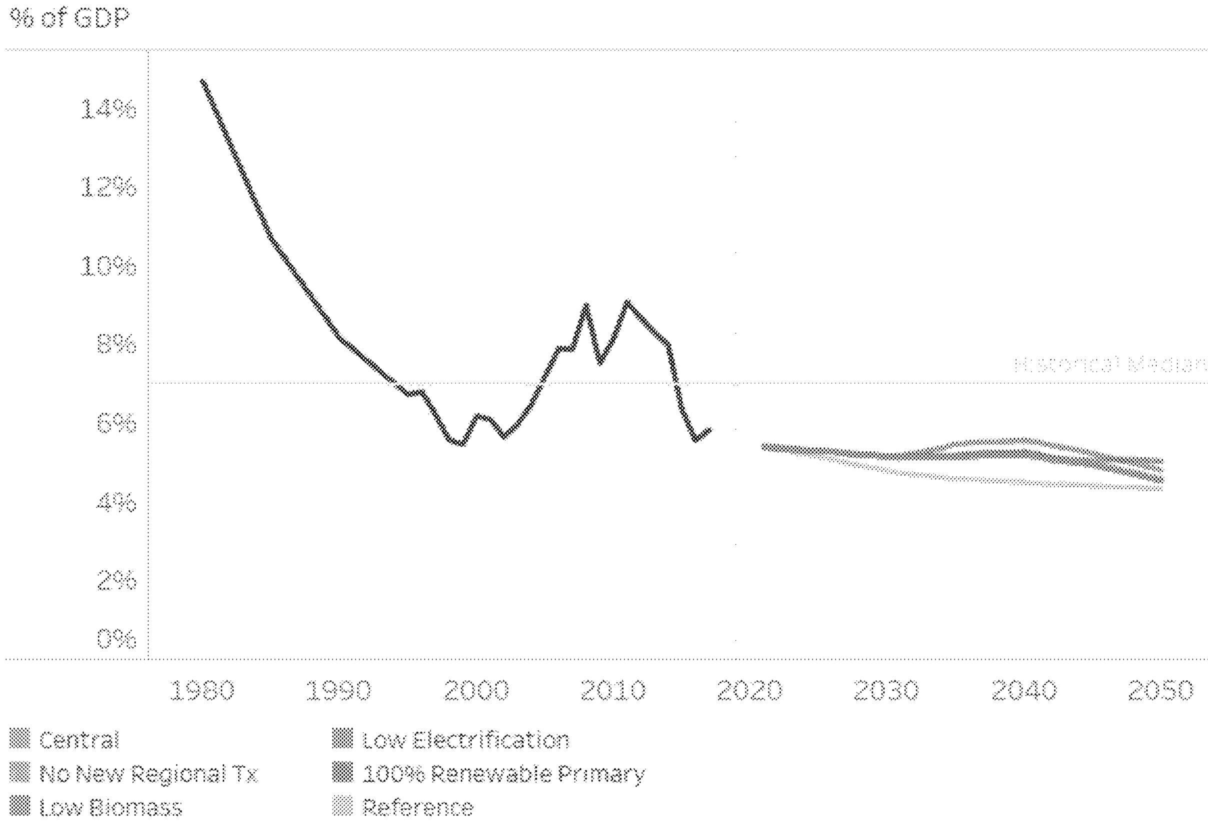
Florida Energy System Results

Energy decarbonization in Florida relies on four principal strategies: (1) **Electricity decarbonization** requires reducing the amount of fossil fuels used for electricity generation, thereby reducing the amount of greenhouse gas emissions from every unit of electricity delivered by about 95% by 2050; (2) **Energy efficiency** is the reduction in energy required to provide energy services such as heating and transportation, and energy use per unit GDP is reduced by about 50% below today's level; (3) **Electrification** involves switching energy uses including transportation and building heating off of fossils fuels and onto low-carbon electricity, and (4) **Capturing carbon** that would otherwise be emitted from power plants and industrial facilities – with the captured carbon either stored permanently (sequestered) or used to create fuels like synthetic natural gas or synthetic diesel, by combining the carbon with renewably-generated hydrogen.

Figure 1 shows historical and projected energy system costs as a share of State Gross Domestic Product (GDP). All scenarios evaluated in this study are in line with historical energy costs in Florida and, even with decarbonization, energy system costs are anticipated to decline as a share of GDP. The highest cost scenario is the 100% Renewable Primary pathway due to the emphasis on displacing *all* fossil fuels by 2050, rather than continuing to use some small amount of the lowest-cost fossil fuels and capturing and storing the associated carbon. The lowest cost scenario is the Central scenario, which allows for the most flexibility in terms of key decarbonization strategies.

Note that the costs within this chart do not reflect any of the macroeconomic benefits of transitioning off of fossil fuels, including improved air quality, avoided climate impacts (like avoided sea level rise), reduced energy price volatility, and energy independence, which could equal or exceed the net costs shown here.

Figure 1. Total energy system costs as percentage of GDP, historical and projected for Florida



Key Actions by Decade

Achieving the transition described above is not expensive but requires significant changes in public policy. Some of the **key policy challenges** that must be managed in all scenarios include: a) managing tradeoffs between using land for low carbon electricity generation (like wind farms and solar arrays) and improving natural carbon storage in forests and soils ; b) electricity market designs that maintain natural gas generation capacity for reliability while using gas generators very infrequently; c) developing electricity rates that incentivize customers to flex their energy use to better match periods of electricity surplus and shortage that come with intermittent renewables like wind and solar; d) encourage the development of carbon capture industries that can leverage periods of excess electricity generation ; e) coordination of planning and policy across sectors that previously had little interaction, such as transportation and electricity; f) coordination of planning and policy across jurisdictions; g) mobilizing investment for a rapid low carbon transition; and e) investing in ongoing modeling, analysis, and data collection that informs both public and private decision-making. These topics are discussed in more detail in *Policy Implications of Deep Decarbonization in the United States.*

Achieving this transformation in Florida by mid-century at lowest cost requires an **aggressive deployment of low-carbon technologies**, including:

2020s

- Begin large-scale transition to electric technologies in key sectors; moving to electric light duty vehicles and electric heat pumps.
- Use coal fired power plants only when absolutely necessary, prioritizing all other sources of electricity generation first. Begin retiring coal assets.
- Ramp up construction of renewable electricity generation and upgrade electricity transmission where needed.
- Allow strategic replacement of natural gas power plants to support rapid deployment of low-carbon generation. These power plants must be financed with the understanding that they will run very infrequently to provide capacity, not as they are operated today.
- Maintain existing nuclear power plants.
- Pilot new technologies that will need to be deployed at scale after 2030.
- Stop developing new infrastructure to transport and process fossil fuels.
- Begin building carbon capture for large industrial facilities.

2030s

- Maximum build-out of renewable electricity generation.
- Nearly 100% of new vehicle sales and new building heating systems using electric technologies.
- Begin large-scale production of biodiesel and bio-jet fuel.
- Large scale carbon capture on industrial facilities.
- Build out electrical energy storage.
- Deploy new natural gas power plants capable of 100% carbon capture if they exist.
- Maintain existing nuclear power plants.
- Continue to reduce generation from gas-fired power plants.

2040s

- Complete the transition to electric technologies for key sectors; virtually 100% of light duty vehicles and building heating systems run on electricity.
- Produce large volumes of hydrogen for use in freight trucks and fuel production.
- Use synthetic fuel production to balance and expand renewable generation.
- Fully deploy biofuel production with carbon capture.
- Further limit gas generation to infrequent periods when needed for system reliability.

Technical Supplement

The following technical supplement shows results for the U.S. as a whole as well as scenario figures not shown in the body of the main report for Florida.

U.S. Results

Figure 30 E&I CO2 emissions trajectories – U.S.

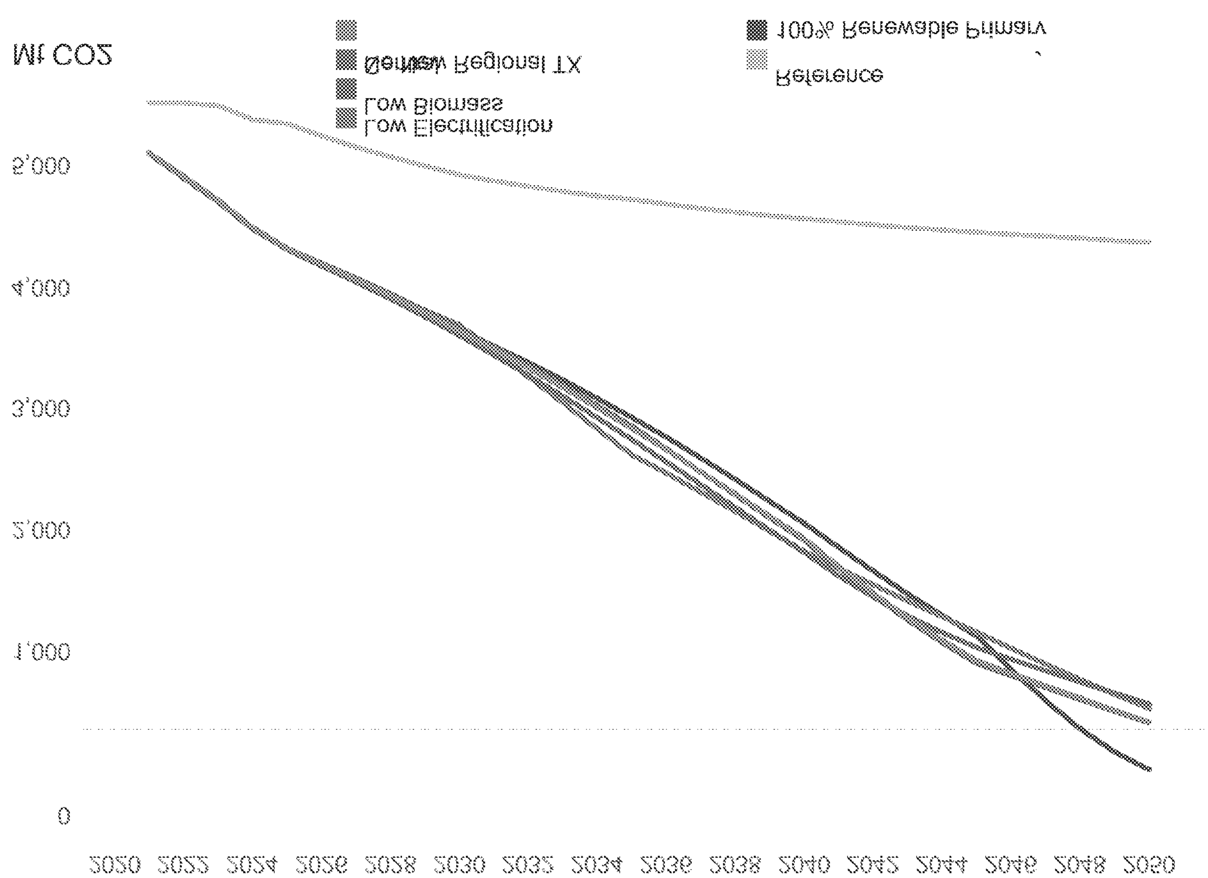


Figure 31 CO2 emissions by final energy/emissions category

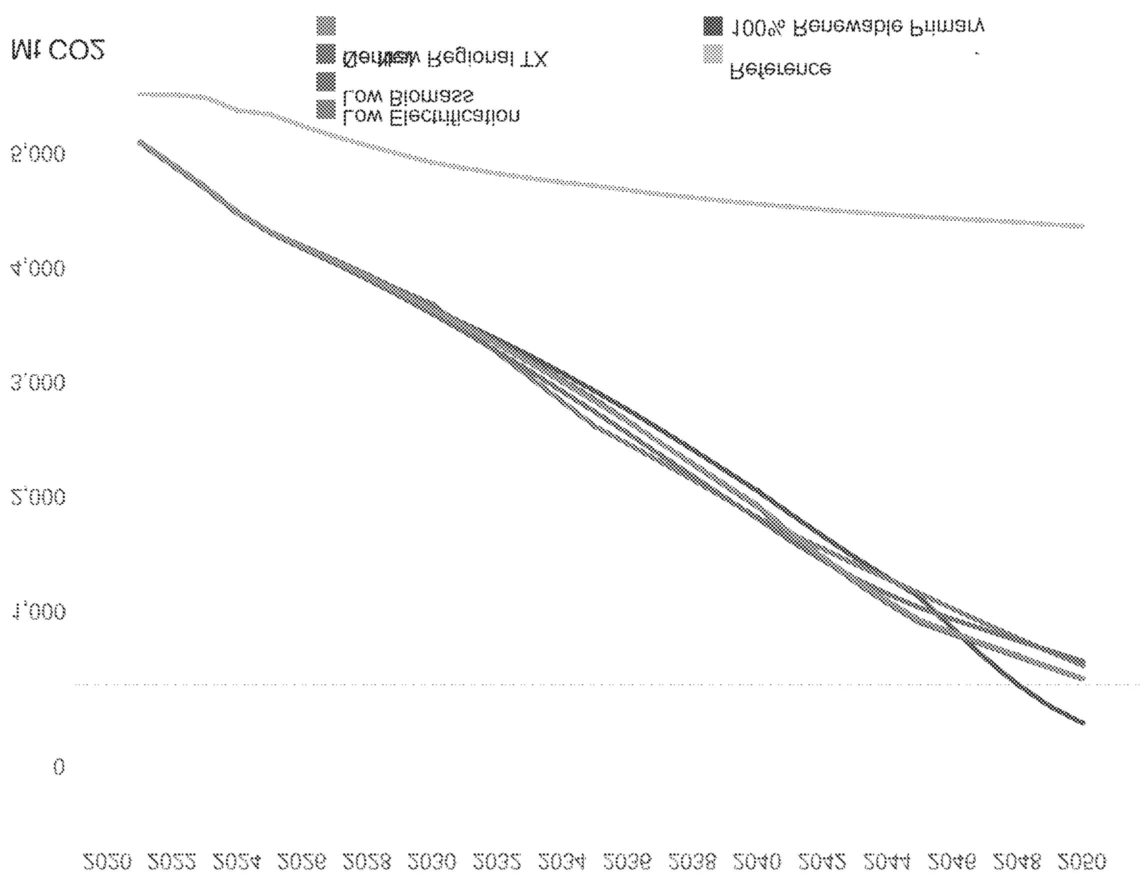
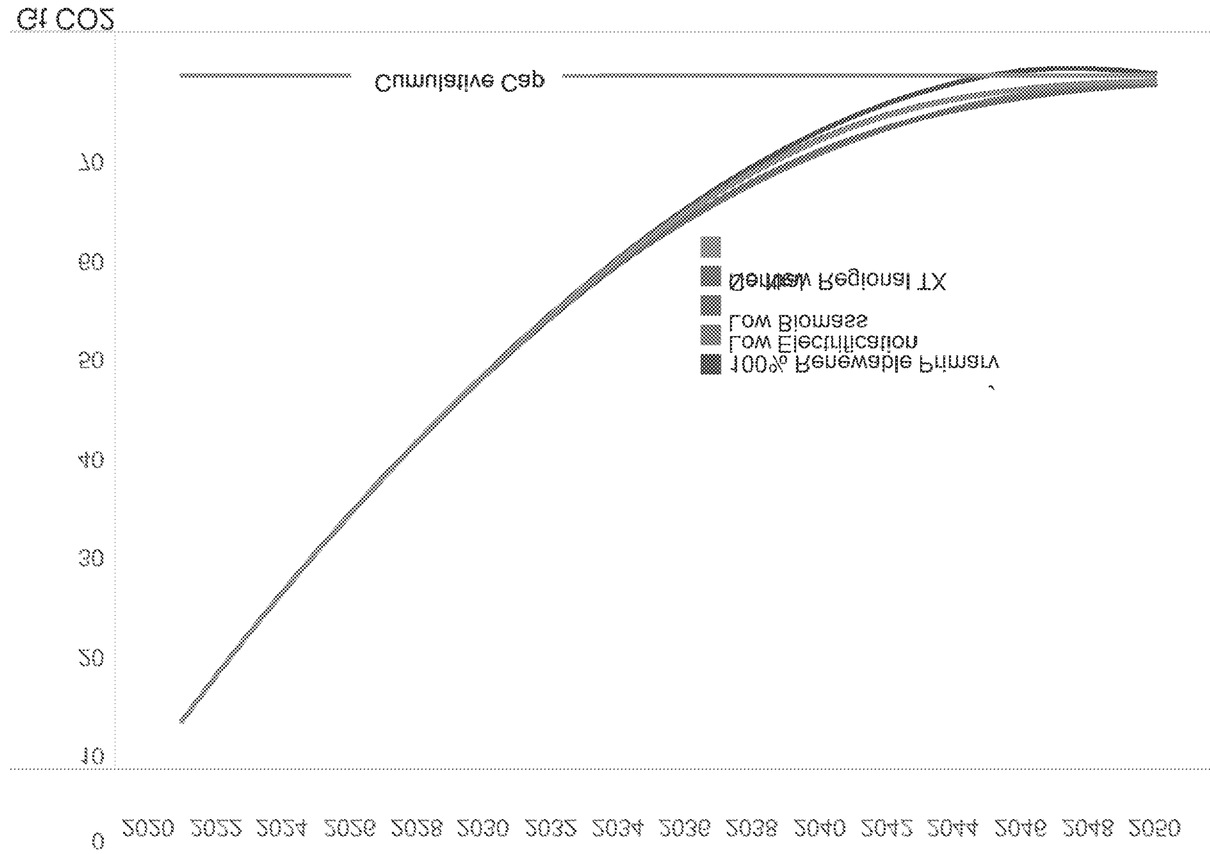


Figure 32 Cumulative E&I CO2 emissions trajectories



EVOLVED ENERGY RESEARCH

Figure 33 Four pillars of deep decarbonization – U.S.

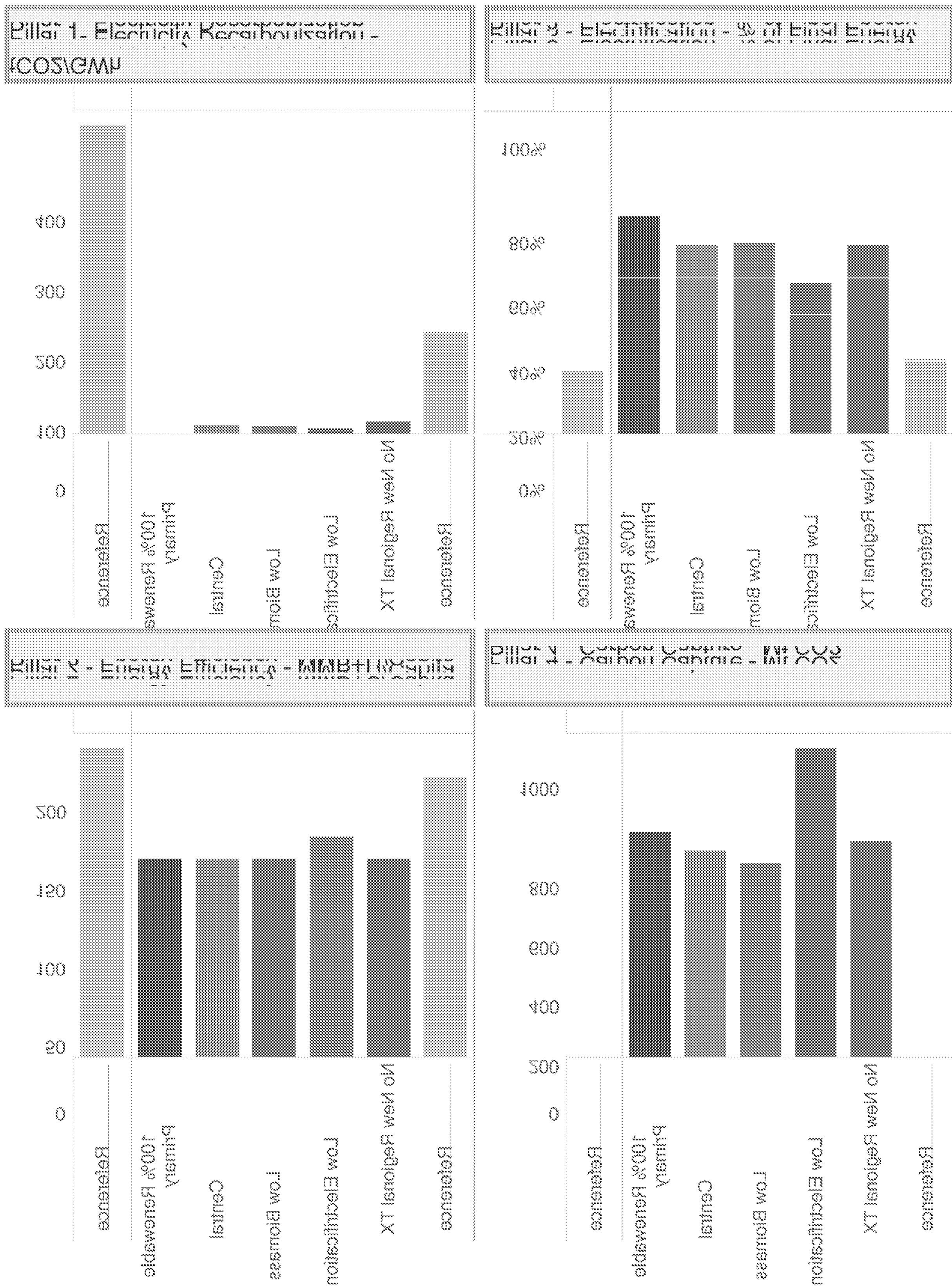


Figure 34 Final and primary energy demand for all scenarios from 2021 – 2050 – U.S.

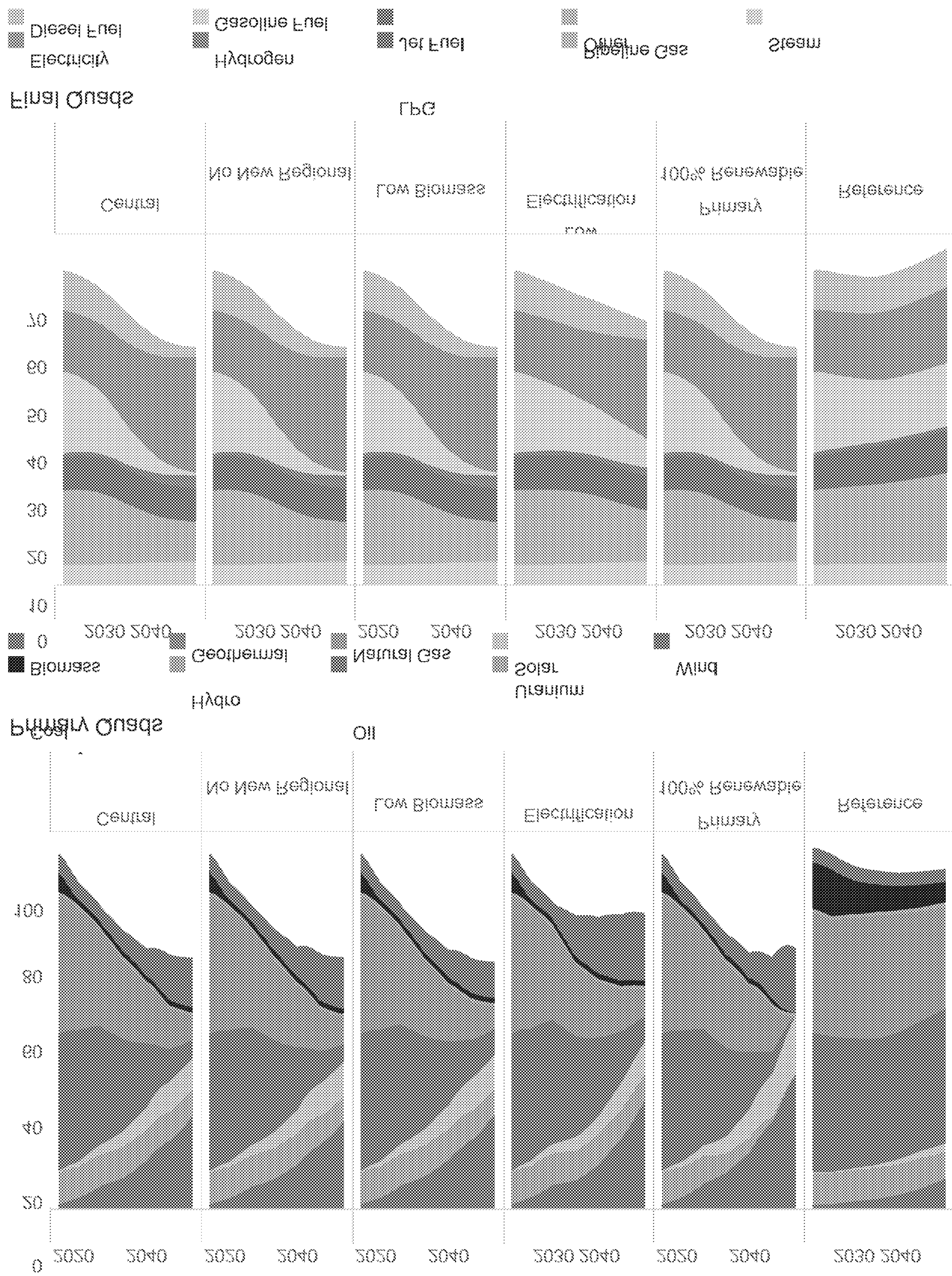


Figure 35 Components of emissions reductions in the Central scenario – U.S.

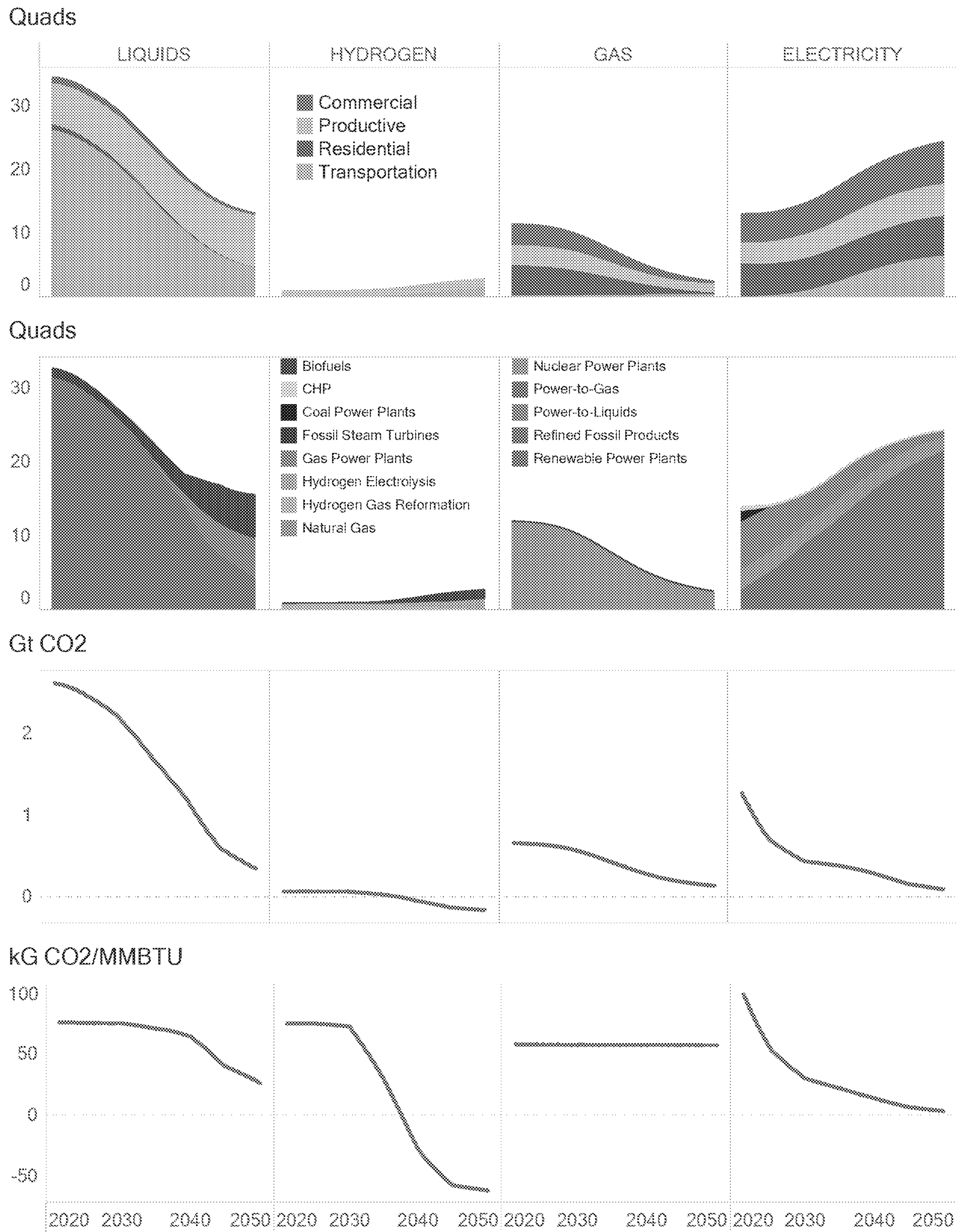


Figure 36 Components of emissions reductions in the Low Biomass scenario – U.S.

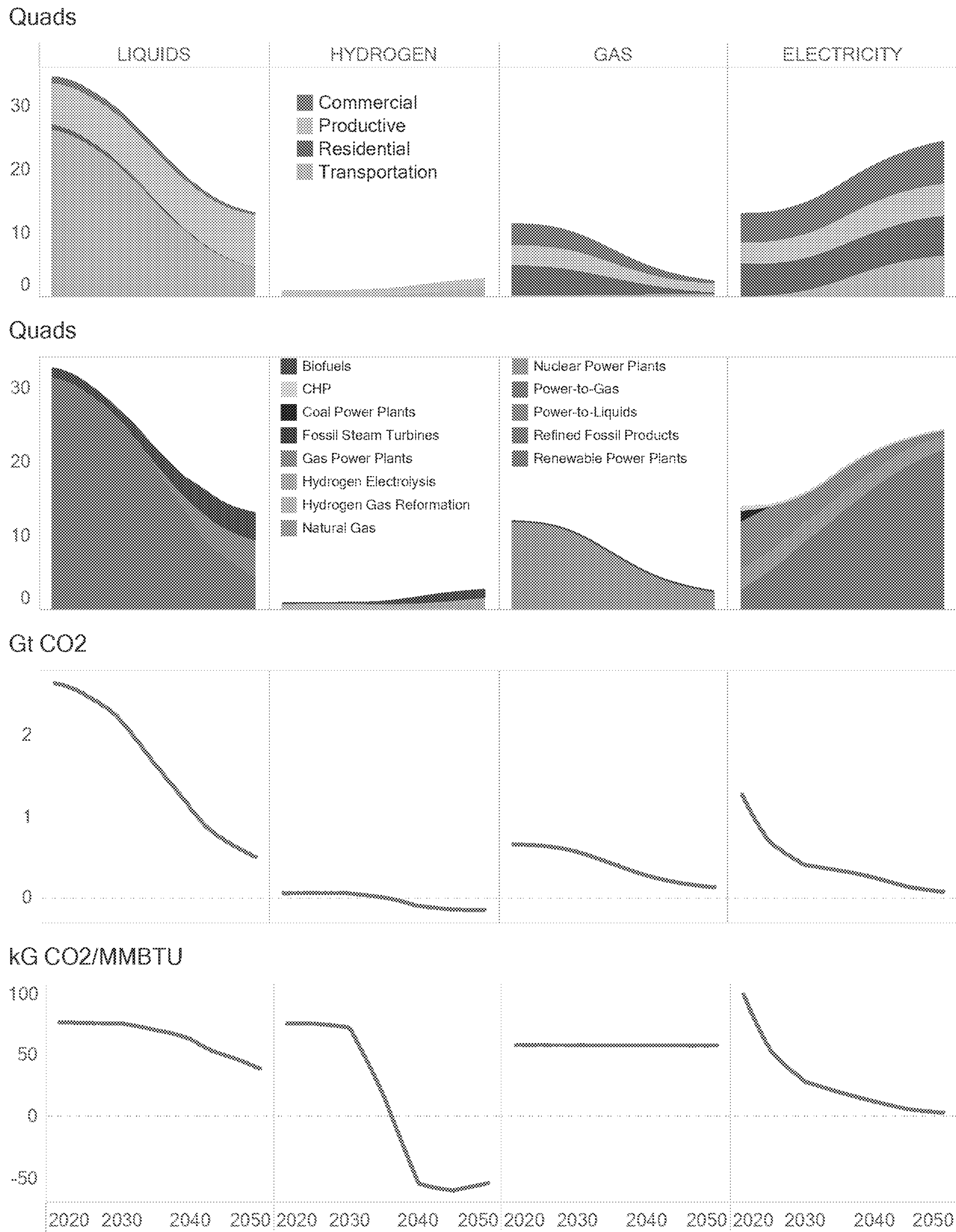


Figure 37 Components of emissions reductions in the Low Electrification scenario – U.S.

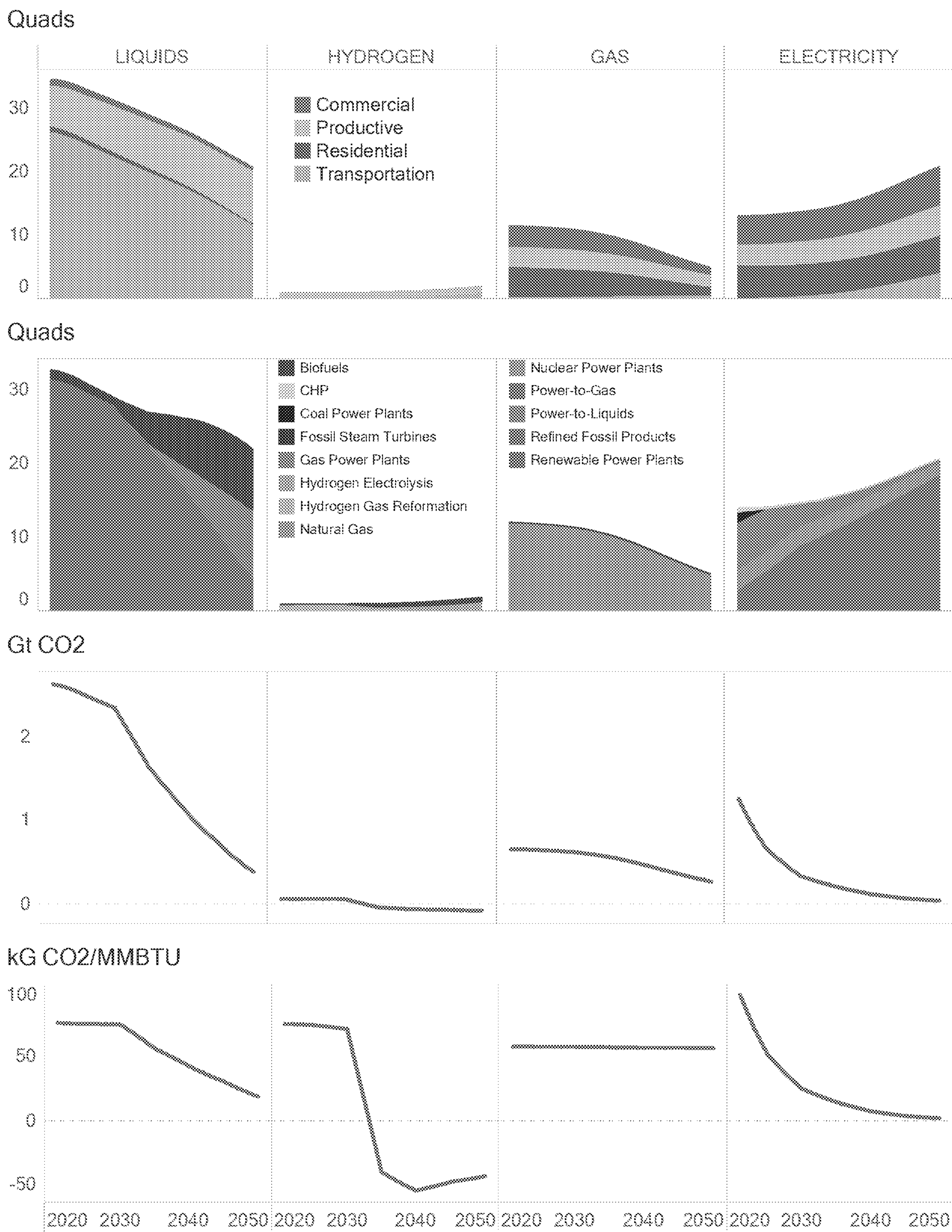


Figure 38 Components of emissions reductions in the No New Regional TX scenario – U.S.

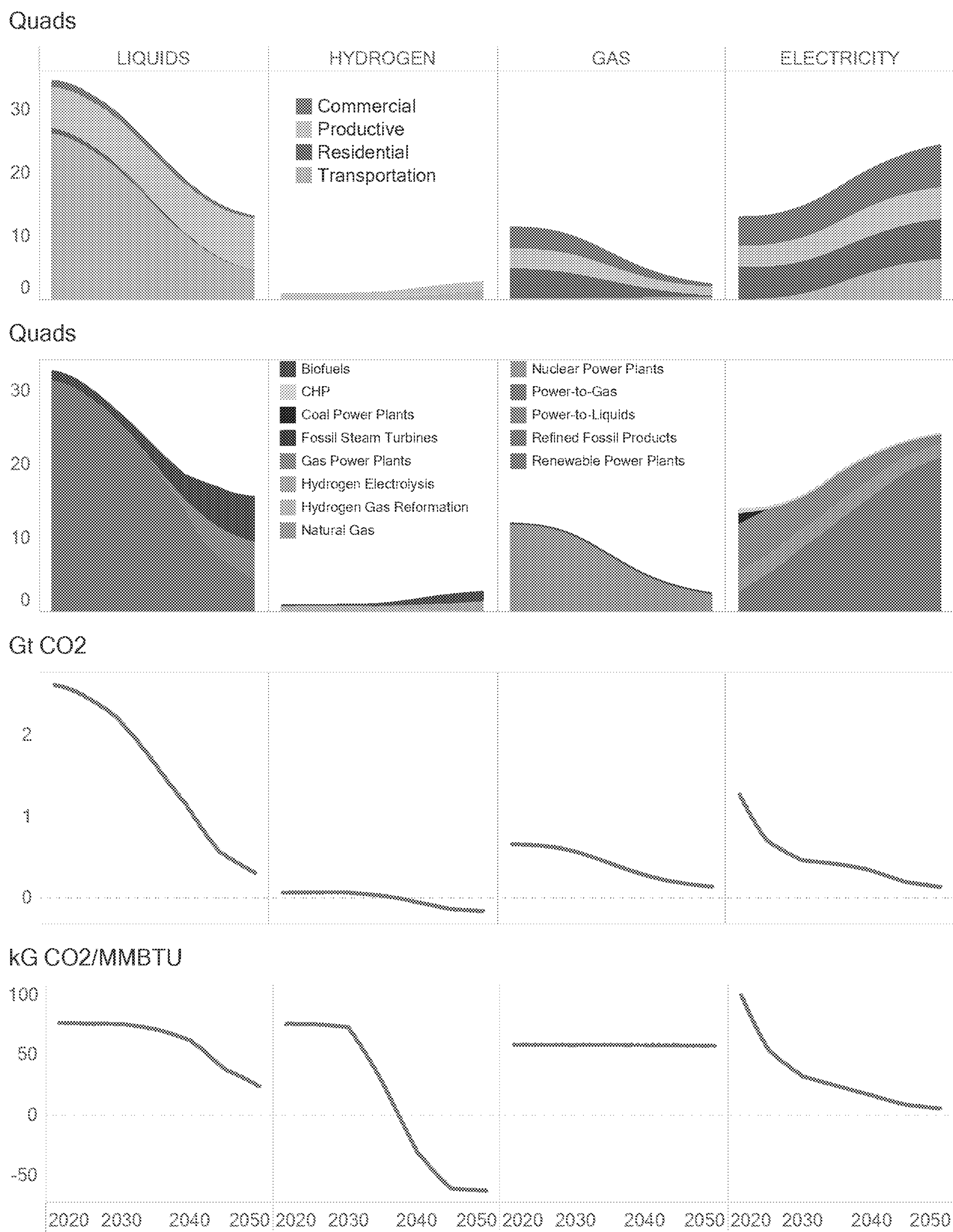


Figure 39 Components of emissions reductions in the 100% Renewable Primary scenario – U.S.

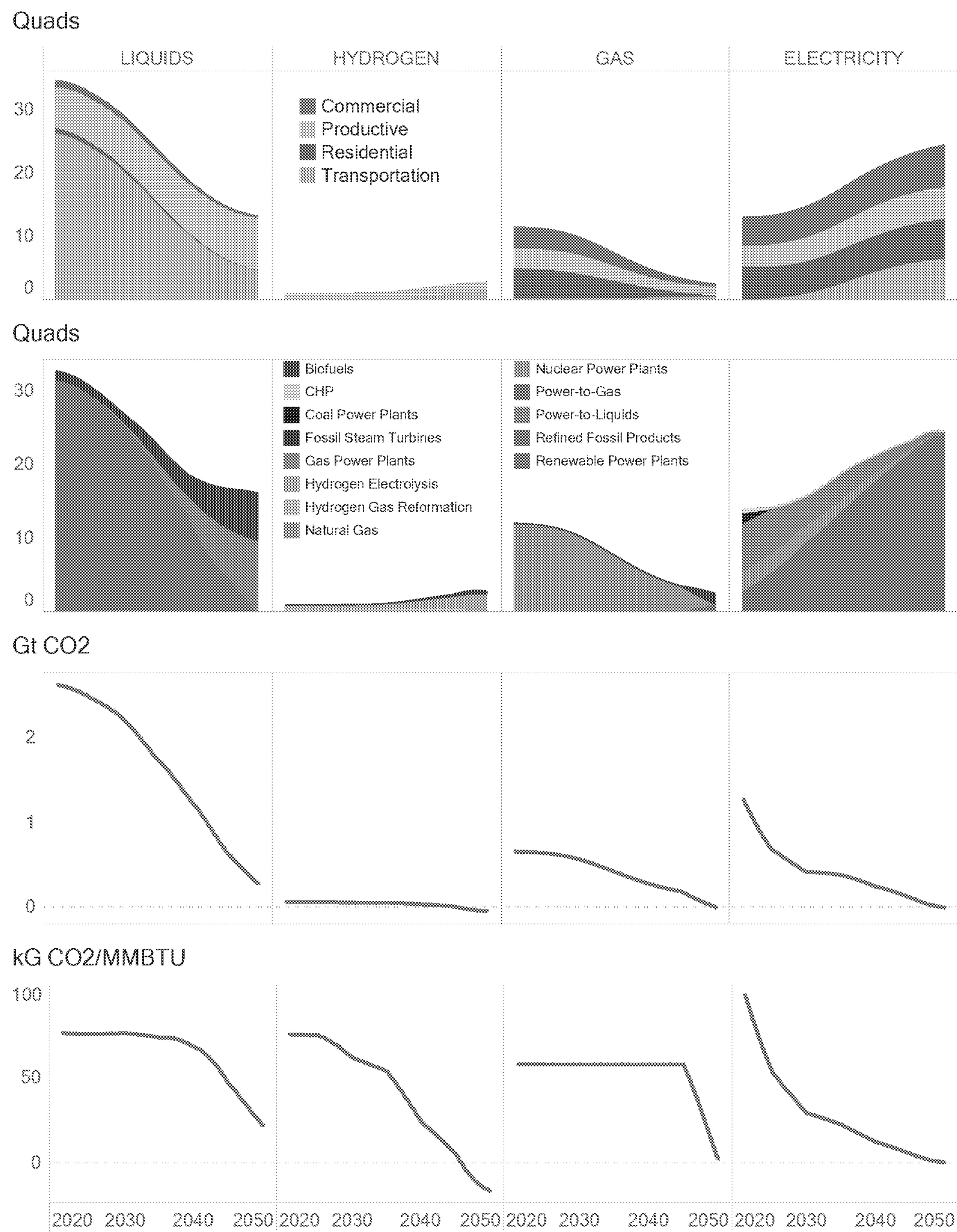


Figure 40 Annual net system cost premium above baseline in $2018 and as % of GDP – U.S.

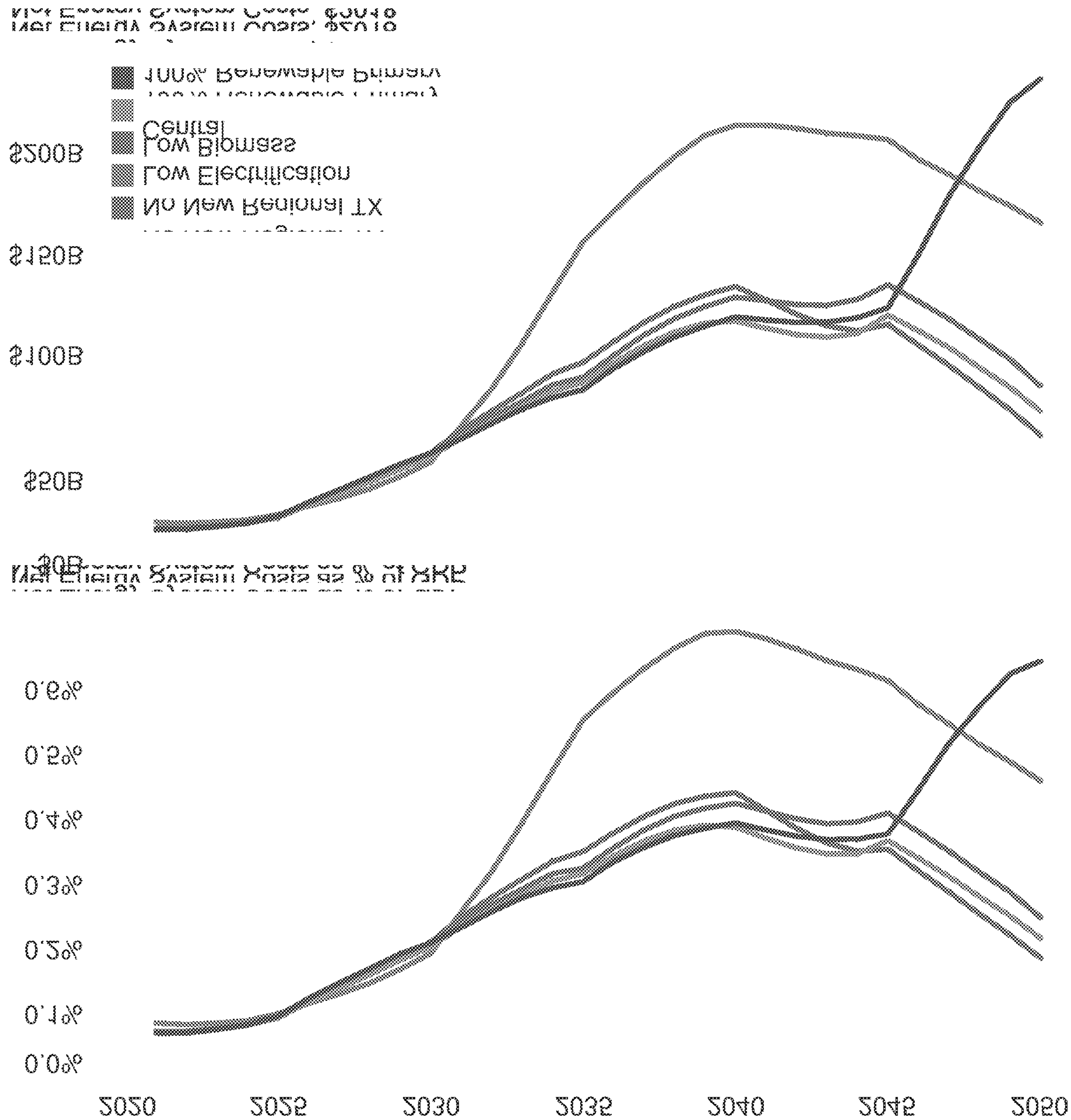


Figure 41 Net Change in E&I System Spending – U.S.

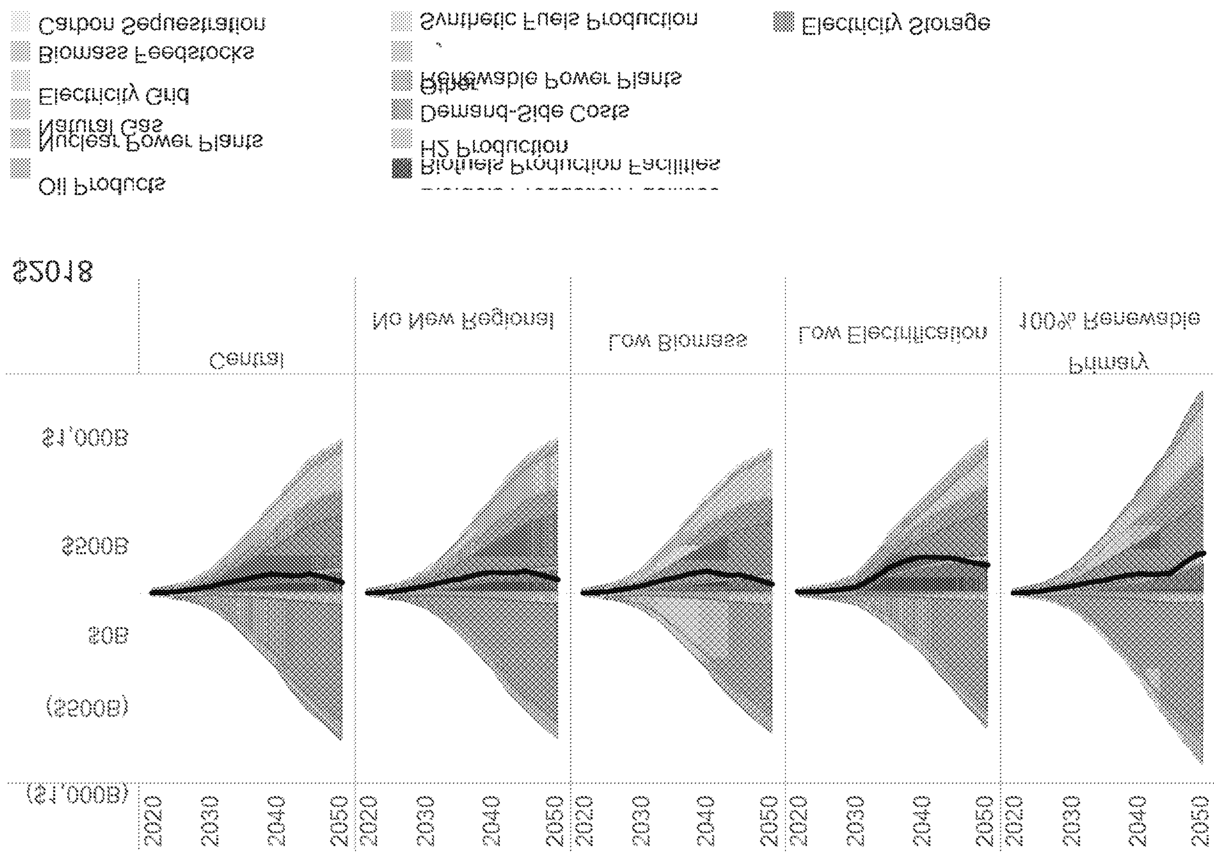
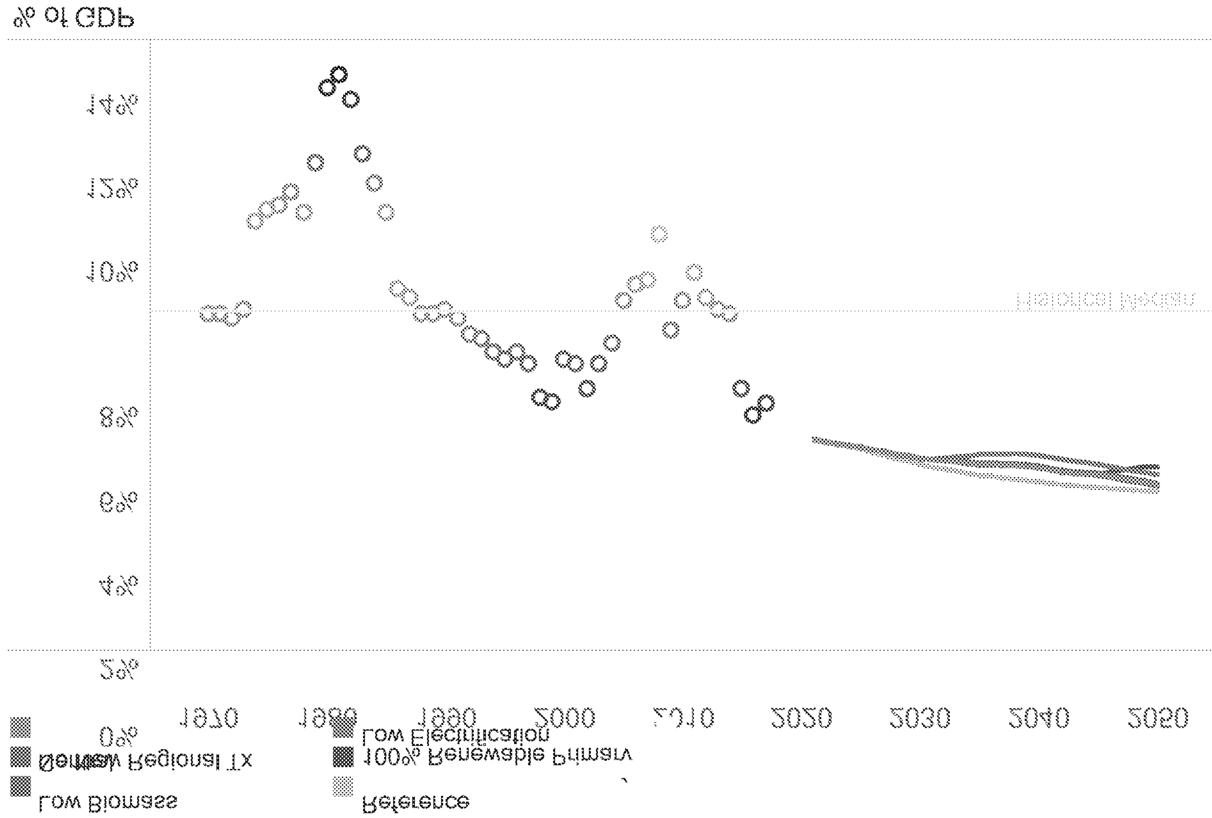


Figure 42 Total energy system costs as % of GDP --historical and projected -- U.S.



Attachment 4

Zero Air Pollution and Zero Carbon From All Energy Without Blackouts at Low Cost in the Whole United States

By Mark Z. Jacobson, Stanford University, April 24, 2021

This infographic summarizes results from simulations that demonstrate the ability of all 50 states and Washington D.C. (Total USA) to match all-purpose energy demand with wind-water-solar (WWS) supply, storage, and demand response continuously every 30 seconds for the years 2050-2051. All-purpose energy is energy for electricity, transportation, buildings, and industry. The ideal transition timeline is 100% WWS by 2035; however, the results here are shown for 2050-2051, after additional population growth has occurred.

WWS electricity-generating technologies include onshore and offshore wind, solar photovoltaics (PV) on rooftops and in power plants, concentrated solar power (CSP), geothermal, hydro, tidal, and wave power. WWS direct heat-sources include geothermal and solar. WWS storage includes electricity, heat, cold, and hydrogen storage. WWS equipment includes electric and hydrogen fuel cell vehicles, heat pumps, induction cooktops, arc furnaces, induction furnaces, resistance furnaces, lawnmowers, etc. No fossil fuels, nuclear bioenergy, or carbon capture is included.

The results are derived from the LOADMATCH grid model using 2050 U.S. state-specific business-as-usual (BAU) and wind-water-solar (WWS) all-sector load data projected from 2018 EIA state load data. The model also uses 30-second resolution WWS supply plus building heating/cooling load data from the GATOR-GCMOM weather-prediction model. The models and results are described, respectively, in the following publications:

Jacobson, M.Z. (2021) On the correlation between building heat demand and wind energy supply and how it helps to avoid blackouts, Smart Energy, 1, 100009, doi:10.1016/j.segy.2021.100009, http://web.stanford.edu/group/efmh/jacobson/Articles/Others/21-Wind-Heat.pdf

Jacobson, M.Z., A.-K. von Krauland, S.J. Coughlin, F.C. Palmer, and M.M. Smith (2021), Zero air pollution and zero carbon from all energy at low cost and without blackouts in variable weather throughout the U.S. with 100% wind-water-solar (WWS) and storage, in review.

Main results. Transitioning the 50 states and D.C. to 100% WWS for all energy purposes…

- **Keeps the grid stable 100% of the time. This is helped by the fact that, during cold storms, winds are stronger (Figure 1) and wind/solar are complementary in nature;**
- **Creates 4.7 million more long-term, full-time jobs than lost;**
- **Saves 53,200 lives from air pollution per year in 2050 in the U.S.;**
- **Eliminates 6,400 million tonnes-CO_2e per year in 2050 in the U.S.;**
- **Reduces 2050 all-purpose, end-use energy requirements by 56.7%;**
- **Reduces the U.S.' 2050 annual energy costs by 62.9% (from \$2,513 to \$933 b/y);**
- **Reduces annual energy, health, plus climate costs by 86.3% (from \$6,800 to \$933 b/y);**
- **Costs ~\$8.94 t upfront. Upfront costs are paid back through energy sales. Costs are for WWS electricity, heat, and H_2 generation; electricity, heat, cold, and H_2 storage; heat pumps for district heating; all-distance transmission; and distribution;**
- **Requires 0.29% of U.S. land for footprint, 0.55% for spacing.**

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Table 1. Reduced End-Use Demand (Load) Upon a Transition From BAU to WWS

1st row: 2018 annually-averaged end-use load (GW) and percentage of the load by sector in the U.S. 2nd row: estimated 2050 total annually-averaged end-use load (GW) and percentage of the total load by sector if conventional fossil-fuel, nuclear, and biofuel use continues to 2050 under a BAU trajectory. 3rd row: estimated 2050 total end-use load (GW) and percent of total load by sector if 100% of BAU end-use all-purpose delivered load in 2050 is instead provided by WWS. Column (i) shows the percent reductions in total 2050 BAU load due to switching from BAU to WWS, including the effects of (f) energy use reduction due to the higher work to energy ratio of electricity over combustion, (g) eliminating energy use for the upstream mining, transporting, and/or refining of coal, oil, gas, biofuels, bioenergy, and uranium, and (h) policy-driven increases in end-use efficiency beyond those in the BAU case. Column (j) is the ratio of electricity load (=all energy load) in the 2050 WWS case to the electricity load in the 2050 BAU case. Whereas Column (j) shows that electricity consumption increases in the WWS versus BAU cases, Column (i) shows that all energy decreases. Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

Scenario	(a) Total annual average end-use load (GW)	(b) Resid-ential percent of total end-use load	(c) Com-mercial per-cent of total end-use load	(d) Indus-try per-cent of total end-use load	(e) Trans-port per-cent of total end-use load	(f) Percent change end-use load w/WWS due to higher work: energy ratio	(g) Percent change end-use load w/WWS due to elim-inating upstream	(h) Percent change end-use load w/WWS due to effic-iency beyond BAU	(i) Overall percent change in end-use load with WWS	(j) WWS: BAU elec-tricity load
Total USA										
BAU 2018	2,404	16.7	13.2	30.5	39.6					
BAU 2050	2,724	14.9	13.8	38.5	32.8					
WWS 2050	1,179	16.6	16.4	47.3	19.6	-37.92	-12.43	-6.35	-56.70	2.03

Table 2. 2050 WWS End-Use Demand by Sector

2050 annual average end-use electric plus heat load (GW) by sector in after energy in all sectors has been converted to WWS. Instantaneous loads can be higher or lower than annual average loads. Values for each region equal the sum over all state values from Table 1. Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

State/region	Total	Residential	Commercial	Transport	Industrial
Total USA	1,179	196.1	193.5	558.4	231.5

Table 3. WWS End-Use Demand by Load Type

Annual average WWS all-sector inflexible and flexible loads (GW) for 2050 in the U.S. "Total load" is the sum of "inflexible load" and "flexible load." "Flexible load" is the sum of "cold load subject to storage," "low-temperature heat load subject to storage," "load for H_2" production, compression, and storage (accounting for leaks as well), and "all other loads subject to demand response (DR)." Annual average loads are distributed in time at 30-s resolution, as described in the text. Instantaneous loads, either flexible or inflexible, can be much higher or lower than annual average loads. Also shown is the annual hydrogen mass needed in each region, estimated as the H_2 load multiplied by 8,760 hr/yr and divided by 59.01 kWh/kg-H_2. Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

State/region	Total end-use load (GW)	Inflex-ible load (GW)	Flex-ible load (GW)	Cold load subject to storage (GW)	Low-temp-erature heat load subject to storage (GW)	Load sub-ject to DR	Load for H_2 (GW)	H_2 needed (Tg-H_2/yr)
Total USA	1,179	598.4	581.1	4.28	44.8	97.4	434.6	14.45

Table 4. Nameplate Capacities Needed by 2050 and Installed as of 2019/2020

Final (from LOADMATCH) 2050 total (existing plus new) nameplate capacity (GW) of WWS generators needed to match power demand with supply, storage, and demand response continuously during 2050-2051 in the U.S. Also provided are nameplate capacities already installed as of 2019 or 2020 end. Nameplate capacity equals the maximum possible instantaneous discharge rate. Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

Year	Onshore wind	Off-shore wind	Resi-dential roof-top PV	Comm /govt rooftop PV	Utility PV	CSP with stor-age	Geoth ermal -elec-tricity	Hydro power	Wave	Tidal	Solar therm al	Geoth ermal heat
2019/20 Total USA	112.57	0.042	13.91	8.74	36.26	1.87	3.85	88.78	0	0	0	0
2050 Total USA	1,116	855.6	686.77	870.2	2,211	7.98	7.65	88.78	9.77	1.28	0	0

11 states imported hydropower in 2019 from Canada. A nameplate capacity of 8,988 MW built in Canada was assigned, based on additional data, to those 11 states as follows: 1,269.3 MW to California; 739 MW to Maine; 3.4 MW to Maryland; 2.2 MW to Massachusetts; 503 MW to Michigan; 1,498.7 MW to Minnesota; 2,299.1 MW to New York; 68.5 MW to North Dakota; 3.4 MW to Ohio; 2,598.1 MW to Vermont; and 3.4 MW to Virginia. Any such nameplate capacities are included in the hydropower nameplate capacities in this table.

Table 5. Capacity Factors of WWS Generators

Simulation-averaged 2050-2051 capacity factors (percent of nameplate capacity produced as electricity before transmission, distribution or maintenance losses) in the U.S. The mean capacity factors in this table equal the simulation-averaged power supplied by each generator in each region (Table 6) divided by the nameplate capacity of each generator in each region (Table 4). Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

Scenario	On-shore wind	Off-shore wind	Rooftop PV	Utility PV	CSP with storage	Geo-thermal elec-tricity	Hydr opow er	Wave	Tidal	Solar therm al	Geo-thermal heat
Total USA	0.379	0.286	0.197	0.208	0.834	0.902	0.501	0.298	0.247	0	0

Capacity factors of offshore and onshore wind turbines account for array losses (extraction of kinetic energy by turbines). The symbol "--" indicates no installation of the technology. Rooftop PV panels are fixed-tilt at the optimal tilt angle of the country they reside in; utility PV panels are half fixed optimal tilt and half single-axis horizontal tracking.

Table 6. Percent of Load Met by Different WWS Generators

Projected simulation-averaged 2050-2051 all-sector WWS energy supply before transmission and distribution losses, storage losses, or shedding losses, in the U.S., and percent of supply met by each generator, based on LOADMATCH simulations. Simulation-average power supply (GW) equals the simulation total energy supply (GWh/yr) divided by the number of hours of simulation. The percentages for each region add to 100%. Multiply each percentage by the 2050 total supply to obtain the GW supply by each generator. Divide the GW supply from each generator by its capacity factor (Table 5) to obtain the 2050 nameplate capacity of each generator needed to meet the supply (Table 4). Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

Scenario	Total WWS supply (GW)	On-shore wind (%)	Off-shore wind (%)	Roof PV (%)	Utility PV (%)	CSP with stor-age (%)	Geoth ermal elec-tricity (%)	Hydr opow er (%)	Wave (%)	Tidal (%)	Solar ther-mal heat (%)	Geo-ther-mal heat (%)
Total USA	1,497	28.24	16.37	20.52	30.77	0.44	0.46	2.97	0.19	0.022	0	0

Table 7. Characteristics of Storage Resulting in Matching Demand With 100% WWS Supply
Maximum charge rates, discharge rate, storage capacity, and hours of storage at the maximum discharge rate of all electricity, cold and heat storage needed for supply + storage to match demand in the U.S. Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

Storage type	Max charge rate (GW)	Max discharge rate (GW)	Max storage capacity (TWh)	Max storage time at max discharge rate (hr)
PHS	59.57	59.57	0.83	14
CSP-elec.	7.98	7.98	--	--
CSP-PCM	12.87	--	0.18	22.6
Batteries	3,920	3,920	15.68	4
Hydropower	43.15	88.78	378.0	4,258
CW-STES	1.71	1.71	0.024	8
ICE	2.57	2.57	0.036	14
HW-STES	59.57	59.57	0.83	8
UTES-heat	7.98	7.98	--	260
UTES-elec.	12.87	--	0.18	--

PHS=pumped hydropower storage; PCM=Phase-change materials; CSP=concentrated solar power; CW-STES=Chilled-water sensible heat thermal energy storage; HW-STES=Hot water sensible heat thermal energy storage; and UTES=Underground thermal energy storage (either boreholes, water pits, or aquifers). The peak energy storage capacity equals the maximum discharge rate multiplied by the maximum number of hours of storage at the maximum discharge rate.

Pumped hydro storage is estimate as the existing (in 2020) nameplate capacity plus the nameplate capacity of pending licenses and of preliminary permits by state (in 2020) (FERC, 2021). If a region has no existing or pending pumped hydro, a minimum of 100 MW is imposed to account for the addition of pumped hydro between 2021 and 2050.

Heat captured in a working fluid by a CSP solar collector can either be used immediately to produce electricity by evaporating water and running it through a steam turbine connected to a generator, stored in a phase-change material, or both. The maximum direct CSP electricity production rate (CSP-elec) equals the maximum electricity discharge rate, which equals the nameplate capacity of the generator. The maximum charge rate of CSP phase-change material storage (CSP-PCM) is set to 1.612 multiplied by the maximum electricity discharge rate, which allows more energy to be collected than discharged directly as electricity. Thus, since the high-temperature working fluid in the CSP plant can be used to produce electricity and charge storage at the same time, the maximum overall electricity production plus storage charge rate of energy is 2.612 multiplied by the maximum discharge rate. This ratio is also the ratio of the mirror size with storage versus without storage. This ratio can be up to 3.2 in existing CSP plants. The maximum energy storage capacity equals the maximum electricity discharge rate multiplied by the maximum number of hours of storage at full discharge, set to 22.6 hours, or 1.612 multiplied by the 14 hours required for CSP storage to charge when charging at its maximum rate.

Hydropower's maximum discharge rate in 2050 is its 2019 nameplate capacity. Hydropower can be recharged only naturally by rainfall and runoff, and its annual-average recharge rate approximately equals its 2019 annual energy output (TWh/yr) divided by the number of hours per year. Hydro is recharged each time step at this recharge rate. The maximum hydropower energy storage capacity available in all reservoirs is also assumed to equal hydro's 2019 annual energy output. Whereas the present table gives hydro's maximum storage capacity, its output from storage during a given time step is limited by the smallest among three factors: the current energy available in the reservoir, the peak hydro discharge rate multiplied by the time step, and the energy required.

The CW-STES peak discharge rate is set equal to 40% of the annual average cold load (for air conditioning and refrigeration) subject to storage. The ICE storage discharge rate is set to 60% of the same annual average cold load subject to storage. The peak charge rate is set equal to the peak discharge rate.

The HW-STES peak discharge rate is set equal to the maximum instantaneous heat load subject to storage during any 30-second period of the two-year simulation. The values have been converted to electricity assuming the electricity produces heat for heat pumps with a coefficient of performance of 4. Because they are based on maximum rather than the annual average loads, they are higher than the annual-average low-temperature heat loads subject to storage in Table 3. The peak charge rate is set equal to the peak discharge rate.

UTES heat stored in underground soil (borehole storage) or water (water pit or aquifer storage) can be charged with either solar or geothermal heat or excess electricity (assuming the electricity produces heat with an electric heat pump at a coefficient of performance of 4). The maximum charge rate of heat (converted to equivalent electricity) to UTES storage (UTES-heat) is set to the nameplate capacity of solar thermal collectors divided by the coefficient of performance of a heat pump=4). When no solar thermal collectors are used, such as in all simulations here, the maximum charge rate for UTES-heat is zero, and UTES is charged only with excess grid electricity running heat pumps. The maximum charge rate of UTES storage using excess grid electricity (UTES-elec.) is set equal to the maximum instantaneous heat load subject to storage during any 30-second period of the two-year simulation. The maximum UTES heat discharge rate is set equal to the maximum instantaneous heat load subject to storage. The maximum charge rate, discharge rate, and capacity of UTES storage are all in units of equivalent electricity that would give heat at a coefficient of performance of 4.

Figure 1. Keeping the Electric Grid Stable With 100% WWS + Storage + Demand Response
2050-2051 hourly time series showing the matching of all-energy demand with supply and storage in the contiguous U.S. (CONUS). First row: modeled time-dependent total WWS power generation versus load plus losses plus changes in storage plus shedding for the full two-year simulation period. Second row: same as first row, but for a window of 100 days during the simulation. Third row: a breakdown of WWS power generation by source during the window. Fourth row: a breakdown of inflexible load; flexible electric, heat, and cold load; flexible hydrogen load; losses in and out of storage; transmission and distribution losses; changes in storage; and shedding. Fifth row: A breakdown of solar PV+CSP electricity production, onshore plus offshore wind electricity production, building total cold load, and building total heat load (as used in LOADMATCH), summed over each region; Sixth row: correlation plots of building heat load versus wind power output and wind power output versus solar power output, obtained from all hourly data during the simulation. Correlations are very strong for R=0.8-1 (R^2=0.64-1); strong for R=0.6-0.8 (R^2=0.36-0.64); moderate for R=0.4-0.6 (R^2=0.16-0.36); weak for 0.2-0.4 (R^2=0.04-0.16); and very weak for 0-0.2 (R^2=0-0.04) (Evans, 1996). The model was run at 30-s resolution. Results are shown hourly, so units are energy output (TWh) per hour increment, thus also in units of power (TW) averaged over the hour. No load loss occurred during any 30-s interval. Raw GATOR-GCMOM results for solar, wind, heat load, and cold load were provided and fed into LOADMATCH at 30-s time increments. LOADMATCH modified the magnitudes, but not time series, of GATOR-GCMOM results, as described in the main text.

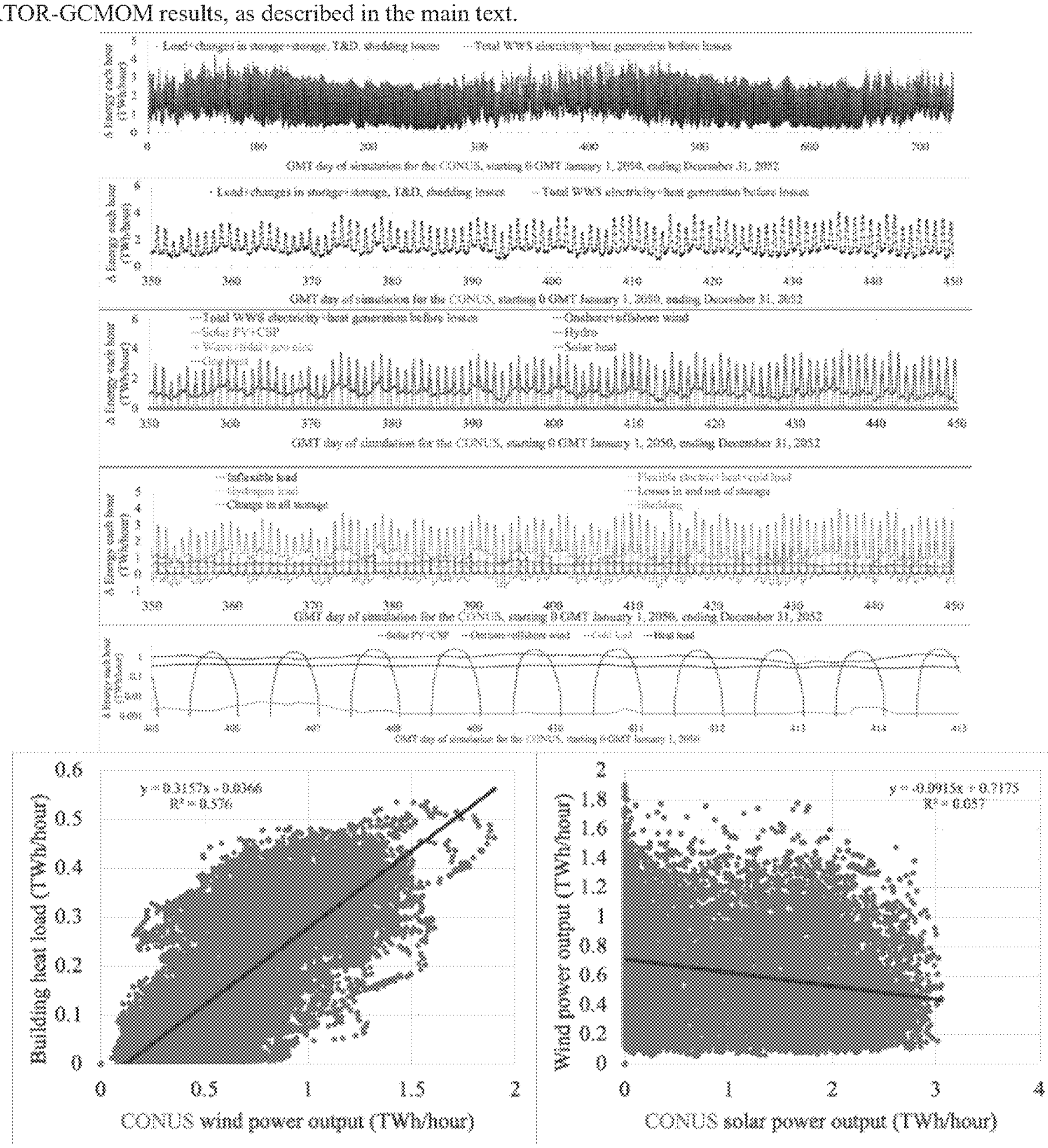

Table 8. Summary of Energy Budget Resulting in Grid Stability

Budget of simulation-averaged end-use power demand met, energy lost, WWS energy supplied, and changes in storage, during the 2-year (17,507.4875 hour) simulations. All units are GW averaged over the simulation and are derived from the data in Table 9 by dividing values from the table in units of TWh per simulation by the number of hours of simulation. TD&M losses are transmission, distribution, and maintenance losses. Wind turbine array losses are already accounted for in the "WWS supply before losses" numbers," since wind supply values come from GATOR-GCMOM, which accounts for such losses. Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

Scenario	(a) Annual average end-use load (GW)	(b) TD&M losses (GW)	(c) Storage losses (GW)	(d) Shedding losses (GW)	(e) End-use load+ losses =a+b+ c+d (GW)	(f) WWS supply before losses (GW)	(g) Changes in storage (GW)	(h) Supply+changes in storage =f+g (GW)
Total USA	1,179	93.86	34.84	190.67	1,499	1,497	1.53	1,499

Table 9. Details of Energy Budget Resulting in Grid Stability

Budget of simulation-total end-use energy demand met, energy lost, WWS energy supplied, and changes in storage, during the 2-year (17,507.4875 hour) simulations. All units are TWh over the simulation. Divide by the number of hours of simulation to obtain simulation-averaged power values, which are provided in Table 8 for key parameters.

	Total USA
A1. Total end use demand	**20,649**
Electricity for electricity inflexible demand	10,600
Electricity for electricity, heat, cold storage + DR	8,344
Electricity for H_2 direct use + H_2 storage	1,705
A2. Total end use demand	**20,649**
Electricity for direct use, electricity storage, + H_2	19,935
Low-T heat load met by heat storage	704
Cold load met by cold storage	9.55
A3. Total end use demand	**20,649**
Electricity for direct use, electricity storage, DR	18,084
Electricity for H_2 direct use + H_2 storage	1,705
Electricity + heat for heat subject to storage	785
Electricity for cold load subject to storage	74.91
B. Total losses	**5,591**
Transmission, distribution, downtime losses	1,643
Losses CSP storage	0.54
Losses PHS storage	0.41
Losses battery storage	329
Losses CW-STES + ICE storage	1.72
Losses HW-STES storage	93
Losses UTES storage	185
Losses from shedding	3,338
Net end-use demand plus losses (A1 + B)	***26,240***
C. Total WWS supply before T&D losses	**26,213**
Onshore + offshore wind electricity	11,695
Rooftop + utility PV+ CSP electricity	13,562
Hydropower electricity	778
Wave electricity	51
Geothermal electricity	121
Tidal electricity	5.534
Solar heat	0

Geothermal heat	0
D. Net taken from (+) or added to (-) storage	**26.7928**
CSP storage	-0.0148
PHS storage	-0.0833
Battery storage	-1.2694
CW-STES+ICE storage	-0.0057
HW-STES storage	0.9042
UTES storage	32.6464
H_2 storage	-5.3844
Energy supplied plus taken from storage (C+D)	***26,240***

End-use demands in A1, A2, A3 should be identical. Generated electricity is shed when it exceeds the sum of electricity demand, cold storage capacity, heat storage capacity, and H_2 storage capacity.

Onshore and offshore wind turbines in GATOR-GCMOM, used to calculate wind power output for use in LOADMATCH, are assumed to be Senvion (formerly Repower) 5 MW turbines with 126-m diameter blades, 100 m hub heights, a cut-in wind speed of 3.5 m/s, and a cut-out wind speed of 30 m/s.

Rooftop PV panels in GATOR-GCMOM were modeled as fixed-tilt panels at the optimal tilt angle of the country they resided in; utility PV panels were modeled as half fixed optimal tilt and half single-axis horizontal tracking. All panels were assumed to have a nameplate capacity of 390 W and a panel area of 1.629668 m^2, which gives a 2050 panel efficiency (Watts of power output per Watt of solar radiation incident on the panel) of 23.9%, which is an increase from the 2015 value of 20.1%.

Each CSP plant before storage is assumed to have the mirror and land characteristics of the Ivanpah solar plant, which has 646,457 m^2 of mirrors and 2.17 km^2 of land per 100 MW nameplate capacity and a CSP efficiency (fraction of incident solar radiation that is converted to electricity) of 15.796%, calculated as the product of the reflection efficiency of 55% and the steam plant efficiency of 28.72%. The efficiency of the CSP hot fluid collection (energy in fluid divided by incident radiation) is 34%.

Table 10. Breakdown of Energy Costs Required to Keep Grid Stable

Summary of 2050 WWS mean capital costs of new electricity plus heat generators; electricity, heat, cold, and hydrogen storage (including heat pumps to supply district heating and cooling), and all-distance transmission/distribution ($ trillion in 2020 USD) and mean levelized private costs of energy (LCOE) (USD ¢/kWh-all-energy or ¢/kWh-electricity-replacing-BAU-electricity) averaged over each simulation. Also shown is the energy consumed per year in each case and the resulting aggregate annual energy cost. Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

	Total USA
Capital cost new generators only ($trillion)	6.835
Cap cost new generators + storage ($trillion)	**8.938**
Components of total LCOE (¢/kWh-all-energy)	
Short-dist. transmission	1.050
Long-distance transmission	0.116
Distribution	2.375
Electricity generators	4.204
Additional hydro turbines	0
Solar thermal collectors	0
LI battery storage	0.774
CSP-PCM + PHS storage	0.002
CW-STES + ICE storage	0.002
HW-STES storage	0.008
UTES storage	0.033
Heat pumps for filling district heating/cooling	0.034
H_2 production/compression/storage	0.430
Total LCOE (¢/kWh-all-energy)	**9.028**
LCOE (¢/kWh-replacing BAU electricity)	8.514
GW annual avg. end-use demand (Table 1)	1,179.5
TWh/y end-use demand (GW x 8,760 h/y)	10,332
Annual energy cost ($billion/yr)	**932.8**

The LCOEs are derived from capital costs, annual O&M, and end-of-life decommissioning costs that vary by technology (and that are a function of lifetime and a social discount rate for an intergenerational project of 2.0 (1-3)%, all divided by the total annualized end-use demand met, given in the present table.

Capital cost of generators-storage-H_2-HVDC ($trillion) is the capital cost of new electricity and heat generators; electricity, heat, cold, and hydrogen storage; hydrogen electrolyzers and compressors; and long-distance (HVDC) transmission.

Since the total end-use load includes heat, cold, hydrogen, and electricity loads (all energy), the "electricity generator" cost, for example, is a cost per unit all energy rather than per unit electricity alone. The 'Total LCOE' gives the overall cost of energy, and the 'Electricity LCOE' gives the cost of energy for the electricity portion of load replacing BAU electricity end use. It is the total LCOE less the costs for UTES and HW-STES storage, H_2, and less the portion of long-distance transmission associated with H_2.

Short-distance transmission costs are $0.0105 (0.01-0.011)/kWh.

Distribution costs are $0.02375 (0.023-0.0245)/kWh.

Long-distance transmission costs are $0.0089 (0.0042-0.010)/kWh (in USD 2020), which assumes 1,500 to 2,000 km HVDC lines, a capacity factor usage of the lines of ~50% and a capital cost of ~$400 (300-460)/MWtr-km.

Table 11. Energy, Health, and Climate Costs of WWS Versus BAU

2050 annual-average end-use (a) BAU load and (b) WWS load; (c) percent difference between WWS and BAU load; (d) present value of the mean total capital cost for new WWS electricity, heat, cold, and hydrogen generation and storage and all-distance transmission and distribution; mean levelized private costs of all (e) BAU and (f) WWS energy (¢/kWh-all-energy-sectors, averaged between today and 2050); (g) mean WWS private (equals social) energy cost per year, (h) mean BAU private energy cost per year, (i) mean BAU health cost per year, (j) mean BAU climate cost per year, (k) BAU total social cost per year; (l) percent difference between WWS and BAU private energy cost; and (m) percent difference between WWS and BAU social energy cost. All costs are in 2020 USD. H=8760 hours per year. Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

Scenario	(a)[1] 2050 BAU Annual avg. end-use load (GW)	(b)[1] 2050 WWS Annual avg. end-use load (GW)	(c) 2050 WWS minus BAU load = (b-a)/a (%)	(d)[2] WWS mean total cap-ital cost ($tril 2020)	(e)[3] BAU mean private energy cost ¢/kWh-all energy	(f)[4] WWS mean private energy cost ¢/kWh-all energy	(g)[5] WWS mean annual all-energy private and social cost = bfH $bil/y	(h)[5] BAU mean annual all-energy private cost = aeH $bil/y	(i)[6] BAU mean annual BAU health cost $bil/y	(j)[7] BAU mean annual climate cost ($bil/y)	(k) BAU mean annual BAU total social cost =h+i+j $bil/y	(l) WWS minus BAU private energy cost = (g-h)/h (%)	(m) WWS minus BAU social energy cost = (g-k)/k (%)
Total USA	2,724	1,179	-56.7	8.94	10.53	9.03	932.8	2,513	700.4	3,578	6,791	-62.9	-86.3

[1]From Table 1.

[2]Capital cost of generators-storage-H_2-HVDC ($trillion) is the capital cost of new electricity and heat generators; electricity, heat, cold, and hydrogen storage; hydrogen electrolyzers and compressors; and long-distance (HVDC) transmission.

[3]This is the BAU electricity-sector cost of energy per unit energy. It is assumed to equal the BAU all-energy cost of energy per unit energy.

[4]The WWS cost per unit energy is for all energy, which is almost all electricity (plus a small amount of direct heat)

[5]The annual private cost of WWS or BAU energy equals the cost per unit energy from Column (f) or (g), respectively, multiplied by the energy consumed per year, which equals the end-use load from Column (b) or (a), respectively, multiplied by 8,760 hours per year.

[6]The 2050 annual BAU health cost equals the number of total air pollution mortalities per year in 2050 from Table 12, Column (a), multiplied by 90% (the estimated percent of total air pollution mortalities that are due to energy) and by a statistical cost of life of $11.56 ($7.21-$17.03) million/mortality (2020 USD) and a multiplier of 1.15 for morbidity and another multiplier of 1.1 for non-health impacts (Jacobson et al., 2019).

[7]The 2050 annual BAU climate cost equals the 2050 CO_2e emissions from Table 12, Column (b), multiplied by the social cost of carbon in 2050 of $548 ($315-$1,188)/metric tonne-$CO_2$ (in 2020 USD), which is updated from values in Jacobson et al. (2019), which were in 2013 USD.

Table 12. Air Pollution Mortalities, Carbon Dioxide Emissions, and Associated Costs

(a) Estimated air pollution mortalities per year in 2050-2051 due to anthropogenic sources (90% of which are energy); (b) carbon-equivalent emissions (CO_2e) in the BAU case; (c) cost per tonne-CO_2e of eliminating CO_2e with WWS; (d) BAU energy cost per tonne-CO_2e emitted; (e) BAU health cost per tonne-CO_2e emitted; (f) BAU climate cost per tonne-CO_2e emitted; (g) BAU total social cost per tonne-CO_2e emitted; (h) BAU health cost per unit all-BAU-energy produced; and (i) BAU climate cost per unit-all-BAU-energy produced. Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

Scenario	(a)[1] 2050 (Deaths/y)	(b)[2] 2050 BAU CO_2e (Mtonne/y)	(c)[3] 2050 WWS ($/ tonne-$CO_2e$-eliminated)	(d)[4] 2050 BAU energy cost ($/ tonne-$CO_2e$-emitted)	(e)[4] 2050 BAU health cost ($/ tonne-$CO_2e$-emitted)	(f)[4] 2050 BAU climate cost ($/ tonne-$CO_2e$-emitted)	(g)[4] 2050 BAU social cost = d+e+f ($/ tonne-$CO_2e$-emitted)	(h)[5] 2050 BAU health cost (¢/kWh)	(i)[5] 2050 BAU climate cost (¢/kWh)
Total USA	53,197	6,408	145.6	392	109.3	558	1,060	2.94	15.0

[1]2050 state mortalities due to air pollution are scaled from 2010-12 state values from Jacobson et al. (2015) using the ratio of the total 2050 air pollution mortalities for the U.S. from Jacobson et al. (2019) 53,199/yr (36,394/yr-73,614/yr) to the total 2010-12 number of deaths across the U.S. from Jacobson et al. (2015) 62,381/yr (19,363/yr-115,723/yr).

[2]CO_2e=CO_2-equivalent emissions. This accounts for the emissions of CO_2 plus the emissions of other greenhouse gases multiplied by their global warming potentials.

[3]Calculated as the WWS private energy and total social cost from Table 11, Column (g) divided by the CO_2e emissions from Column (b) of the present table.

[4]Columns (d)-(g) are calculated as the BAU private energy, health, climate, and total social costs from Table 11, Columns (h)-(k), respectively, each divided by the CO_2e emissions from Column (b) of the present table.

[5]Columns (h)-(i) are calculated as the BAU health and climate costs from Table 11, Columns (i)-(j), respectively, each divided by the BAU end-use load from Table 11, Column (a) and by 8760 hours per year.

Table 13. Land Areas Needed

Footprint areas for *new* utility PV farms, CSP plants, solar thermal plants for heat, geothermal plants for electricity and heat, and hydropower plants and spacing areas for new onshore wind turbines. Results are shown for the Total USA, which is the sum of results for the contiguous U.S. (CONUS) plus those for Alaska and Hawaii.

Scenario	State or region land area (km^2)	Footprint Area (km^2)	Spacing area (km^2)	Footprint area as percentage of state or region land area (%)	Spacing area as a percentage of state or region land area (%)
Total USA	9,161,891	26,763	50,655	0.29	0.55

Spacing areas are areas between wind turbines needed to avoid interference of the wake of one turbine with the next. Such spacing area can be used for multiple purposes, including farmland, rangeland, open space, or utility PV. Footprint areas are the physical land areas, water surface areas, or sea floor surface areas removed from use for any other purpose by an energy technology. Rooftop PV is not included in the footprint calculation because it does not take up new land. Conventional hydro new footprint is zero because no new dams are proposed as part of these roadmaps. Offshore wind, wave, and tidal are not included because they don't take up new land. Areas are given both as an absolute area and as a percentage of the state or regional land area, which excludes inland or coastal water bodies. For comparison, the total area and land area of Earth are 510.1 and 144.6 million km^2, respectively.

Table 14. Changes in the Employment

Estimated long-term, full-time jobs created and lost due to transitioning from BAU energy to WWS across all energy sectors in the Total USA (the sum of results from the contiguous U.S. (CONUS) plus those from Alaska and Hawaii). The job creation accounts for new jobs in the electricity, heat, cold, and hydrogen generation, storage, and transmission (including HVDC transmission) industries. It also accounts for the building of heat pumps to supply district heating and cooling. However it does not account for changes in jobs in the production of electric appliances, vehicles, and machines or in increasing building energy efficiency. Construction jobs are for new WWS devices only. Operation jobs are for new and existing devices. The losses are due to eliminating jobs for mining, transporting, processing, and using fossil fuels, biofuels, and uranium. Fossil-fuel jobs due to non-energy uses of petroleum, such as lubricants, asphalt, petrochemical feedstock, and petroleum coke, are retained. For transportation sectors, the jobs lost are those due to transporting fossil fuels (e.g., through truck, train, barge, ship, or pipeline); the jobs not lost are those for transporting other goods. The table does not account for jobs lost in the manufacture of combustion appliances, including automobiles, ships, or industrial machines.

Scenario	Construction jobs produced	Operation jobs produced	Total jobs produced	Jobs lost	Net change in jobs
Total USA	3,598,373	3,934,347	7,532,721	2,840,006	4,692,715

Attachment 5

EXPERT REPORT
OF
SUSAN E. PACHECO, MD
and JEROME A. PAULSON, MD, FAAP

Kelsey Cascadia Rose Juliana; Xiuhtezcatl Tonatiuh M.,
through his Guardian Tamara Roske-Martinez; et al.,
Plaintiffs,

v.

The United States of America; Donald Trump,
in his official capacity as President of the United States; et al.,
Defendants.

IN THE UNITED STATES DISTRICT COURT
DISTRICT OF OREGON

(Case No.: 6:15-cv-01517-TC)

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TABLE OF ACRONYMS AND ABBREVIATIONS

AAP:	American Academy of Pediatrics
ACEs:	adverse childhood experiences
ACOS:	asthma–chronic obstructive pulmonary disease overlap syndrome
CDC:	Centers for Disease Control and Prevention
CEHM:	Children's Environmental Health Network
CHPAC:	Children's Health Protection Advisory Committee
CO:	carbon monoxide
CO_2:	carbon dioxide
COEH:	Council on Environmental Health
COPD:	chronic obstructive lung disease
DEQ:	Department of Environmental Quality
EPA:	U.S. Environmental Protection Agency
ER:	emergency room
FEV1:	forced expiratory volume
FVC:	forced vital capacity
GAO:	U.S. Government Accountability Office
GW:	George Washington University
HAB:	harmful algal bloom
HIA:	health impact assessment
IARC:	International Agency for Research on Cancer
ICU:	intensive care unit
ICD-10-CM:	International Classification of Diseases, 10th Revision, Clinical Modification
IPCC:	Intergovernmental Panel on Climate Change
MACCHE:	Mid-Atlantic Center for Children's Health & the Environment
MRI:	magnetic resonance imaging
NCEH:	National Center for Environmental Health
NO:	nitric oxide
NO_2:	nitrogen dioxide
O_3:	ozone
PAHs:	polycyclic aromatic hydrocarbons
PEF:	peak expiratory flow
PEHSU:	pediatric environmental health specialty unit
PM:	particulate matter
PM2.5:	particulate matter less than 2.5 micrometers
SO_2:	sulfur dioxide
TENDR:	Targeting Environmental Neurodevelopmental Risks
TRAP:	traffic-related air pollution
UGE:	unconventional natural gas extraction
UGRB:	Upper Green River Basin
USGCRP:	U.S. Global Change Research Program
VCCA:	Virginia Clinicians for Climate Action
VOC:	volatile organic compounds
WMH:	white matter hyperintensities

INTRODUCTION

We, Dr. Susan Pacheco and Dr. Jerome Paulson, have been retained by Plaintiffs in the above captioned matter to provide expert opinion on the public health impacts on children from climate change and air pollution. We conclude that there is abundant evidence, both in the literature and from our clinical experience, that the health of children is already being adversely impacted as a result of climate change and air pollution.

We, Dr. Susan Pacheco and Dr. Jerome Paulson, are co-authoring this report and, unless otherwise specified within, we share the opinions expressed herein. The opinions expressed in this report are our own, and not the opinions of any of the institutions for which we work or donate our time. The opinions expressed herein are based on the data and facts available to us at the time of writing and are to a reasonable degree of scientific certainty, unless otherwise specifically stated. Should additional relevant or pertinent information become available, we reserve the right to supplement the discussion and findings in this expert report in this action.

Dr. Pacheco's CVs is contained in **Exhibit A** and Dr. Paulson's CV is contained in **Exhibit B** to our expert report in this action. The list of publications we have authored within the last ten years are included in our CVs. A statement of Dr. Paulson's previous testimony within the preceding four years as an expert at trial or by deposition is contained in **Exhibit C** to our expert report. Dr. Pacheco has not given previous testimony within the preceding four years as an expert at trial or by deposition. In preparing this report, we have reviewed a number of documents. Our report contains a list of citations to the documents that we have used or considered in forming our opinions, listed in **Exhibit D**.

In preparing our expert report and testifying at trial, we are not receiving any compensation and are providing our expertise pro bono to the Plaintiffs given the financial circumstances of these young Plaintiffs. Given the magnitude of the threat that children are facing, including these Plaintiffs, we also feel compelled to share our expertise in this important case.

EXECUTIVE SUMMARY

The federal government has known about the threats posed by climate change and air pollution for decades. In addition to the federal government's knowledge that fossil fuels are causing dangerous climate change impacts, like heat waves, sea level rise, and extreme weather events, the government also knows that climate change and air pollution from fossil fuels is harming the health of children. Children are uniquely vulnerable to the impacts of climate change due to their physiological features, including their higher respiratory rate, lung growth and development, immature immune system, higher metabolic demands, and immature central nervous system. Children also spend more time playing outside than adults, which exposes them to excess heat, polluted air, and disease carrying insects. Consistent with the literature, including reports by the federal government, it is our expert opinion that the health of children is already being severely impacted by climate change and air pollution. The adverse health impacts will continue to get more severe, and impact a growing number of children, unless the use of fossil fuels is promptly phased out. Because there is no comprehensive method or database that allows us to track health issues connected to climate change, we expect that climate change and air pollution are going under-diagnosed as a factor impacting the health of children.

While all children are uniquely vulnerable to the impacts of climate change and air pollution, certain populations of children are especially vulnerable, including those vulnerable to sea level rise, children with preexisting medical conditions, children from communities of color, and economically disadvantaged children. All of the Plaintiffs in this case are children, and some are from these especially vulnerable population of children.

There are a variety of way in which climate change is harming these Plaintiffs, and other children. Climate change is causing an increase in average temperature and heat waves, with a resulting increase in morbidity and mortality for children. The excess heat can impact children's neurological development and make it harder for them to attend school and play outside. Extreme weather events, like hurricanes, can result in the displacement of children and disrupt their school and social support networks. They also frequently cause children to be exposed to toxic substances in flood waters, and mold in water-damaged buildings, both of which have acute and chronic health impacts. Meanwhile, the increasing frequency and severity of wildfires is decreasing air quality, which is harmful to all children, and especially those with asthma and allergies. Children are increasingly exposed to infectious disease as the range of disease-carrying organisms expands due to climate change. Climate change is also contributing to food, water, and nutrient insecurity and scarcity, which can, among other things, increase the risk of malnutrition for children. Finally, the health of children is being harmed by a decrease in water quality and an increase in algal blooms, which make children sick when exposed to contaminated water.

In addition to being harmed by climate change impacts, children's health is adversely impacted by the extraction and combustion of fossil fuels, the primary driver of climate change. Air pollutants associated with fossil fuels, including particulate matter and ozone, as associated with higher morbidity and mortality in children. Air pollution impacts children's neurological development, exacerbates existing respiratory illnesses, such as asthma, and cause new respiratory illnesses.

The health impacts on children from climate change and air pollution will be life-long, and will also impact future generations. There is abundant evidence that children exposed to traumatic events, often referred to as adverse childhood experiences (ACEs), experience long-term health impacts and that ACEs can contribute to an early death. We agree. Climate change and air pollution can also cause long-term cognitive and behavioral impacts, which diminishes children's ability to learn, and ultimately prosper in life. We have never before had entire generations of children growing up in an environment so altered and degraded by climate change and air pollution. In our expert opinion, the severity and scope of the harm to children's health will continue to increase in coming years unless the federal government responds to the threats posed by climate change and air pollution. Indeed, addressing the underlying cause of the health impacts on children, climate change and air pollution, is the only way to properly respond to this health crisis.

QUALIFICATIONS

Qualifications of Susan E. Pacheo, MD

I obtained a bachelor's degree in Biology at the University of Puerto Rico in Mayagüez and a medical degree at the University of Puerto Rico Medical School in San Juan, Puerto Rico. I did my internship in pediatrics at Louisiana State University in New Orleans. In 1989 I moved to Houston, Texas and completed my residency training in pediatrics at Baylor College of Medicine and subspecialty in Pediatric Allergy and Immunology (1992) at the same institution. I am board certified in Pediatrics and have certified in Allergy and Immunology three times, the last one in 2015. I have worked in academia all my life including Baylor College of Medicine and the University of Texas McGovern Medical School at the Houston Medical Center.

In the context of my over 20 years of practice in allergy and immunology I have taken care of a pediatric population with asthma, allergies, and immunodeficiency and have seen up close how air pollution, climate change, environmental exposures, and concerns about infections continue to shape their life. My interest in air pollution and climate change led me to join the medical advisory board of the American Lung Association Texas chapter. I implemented one of their initiatives at the University of Texas and other pediatric practices in Houston to improve asthma care in a group of underserved pediatric patients in these practices. I am in the process of developing a pediatric asthma clinic at the university that will be centered around education, including air pollution and prevention of environmental exposures to enhance asthma control.

In 2013, I received the White House Champion of Change Award for my work to raise awareness of climate-related health impacts. I was elected to join the American Academy of Pediatrics (AAP) Council of Environmental Health executive committee in 2014 and co-authored the 2015 AAP's technical report "Global Climate Change and Children's Health." My climate change-related activities have been centered around education in the medical community as this was a neglected subject in the climate conversation some years ago. I have focused my expertise around the effects of climate change on human health including respiratory diseases. I continue to teach on this subject at the regional, national and international level and as part of my academic responsibilities at the university to first and second year medical students, students in the global health concentration, pediatric residents and pediatric faculty. I have given over 75 presentations on the health effects of climate change.

Qualifications of Jerome A. Paulson, MD, FAAP

I graduated with honors and with general honors from the University of Maryland at College Park with a Bachelor of Science degree in biochemistry. I graduated from Duke University with an MD degree and did my house staff training in Pediatrics at the Johns Hopkins Hospitals and Sinai Hospital, both in Baltimore, MD. I also completed a one-year fellowship in ambulatory pediatrics at Sinai Hospital.

I was first introduced to environmental health during my residency training. Like most pediatric residents who trained in a large city in the mid-1970s, I learned about lead poisoning because it was a common clinical problem at the time. My first position after residency was as Assistant

Professor of Pediatrics at Case Western Reserve University – Rainbow Babies & Children's Hospital. In addition to many other responsibilities, I became the hospital's expert on childhood lead poisoning and a consultant to the Cuyahoga County Health Department on lead poisoning.

After relocating to Washington, DC and then, in 1990, joining the faculty of the George Washington University (GW) School of Medicine and Health Sciences, I again took on the role of lead poisoning expert for the pediatricians who were part of the Department of Health Care Sciences. Through self-education, attending a number of continuing education meetings and several professional responsibilities that I will enumerate, I expanded my expertise to encompass the new field of research, education, advocacy and clinical care that is known as "children's environmental health."

At GW, in addition to my appointment as Associate Professor in the Department of Health Care Sciences, I also was appointed an Associate Professor in the Department of Pediatrics. I also taught in the medical school's public health program and became a faculty member in the Milken Institute School of Public Health when it was chartered.

When the Department of Health Care Sciences at the GW School of Medicine and Health Sciences was dissolved, my primary academic appointment ultimately moved to the department of Pediatrics in the School of Medicine. In 2015, I resigned from my positions and was appointed Professor Emeritus in the Department of Pediatrics at the GW University School of Medicine and Health Sciences and Professor Emeritus in the Department of Environmental & Occupational Health in the GW University Milken Institute School of Public Health.

During the 1999-2000 academic year, I served as a special assistant to the director of the National Center for Environmental Health ("NCEH") of the Centers for Disease Control and Prevention ("CDC"). I worked on a number of issues related to children's environmental health for the director. I then received a fellowship that allowed me to work with the Children's Environmental Health Network ("CEHN") for two years on a broad range of children's environmental health issues.

In 2000, in conjunction with two colleagues, I created the Mid-Atlantic Center for Children's Health & the Environment ("MACCHE"). We were the third (of now 10) pediatric environmental health specialty units ("PEHSUs") funded in the U.S. The role of MACCHE is to educate health professional and others in the Mid-Atlantic region about issues related to children's health and the environment; and the organization serves as a consultant to parents, health care providers, government agencies and others on issues related to the environment and children's health. In 2015, I transitioned out of a leadership role at the MACCHE, and now serve as their pediatric consultant.

In 2007, I was appointed by the board of directors of the American Academy of Pediatrics (AAP) to serve on the Executive Committee of the Academy's Council on Environmental Health ("COEH"); and in 2011, I was elected by my peers to chair that committee. I completed my term on the COEH in 2015. In 2007, I was also appointed by the U.S. EPA to serve on the Children's Health Protection Advisory Committee ("CHPAC"). I served the maximum 6 years on CHPAC.

In 2007, the AAP became the first medical professional society to develop a policy statement on climate change. While I was not involved in the publication of that document, I did publish, along with Dr. Kris Ebi, Global Climate Change and It's Impact on Children. *Pediatric Clinics of North America.*2007; 54: 213-226. Several years later, Dr Ebi and I published Climate Change and Child Health in the United States. Current Problems in Pediatric & Adolescent Health Care. 2010; 40: 2-18. During my tenure as chair of the COEH, I supervised the drafting of the new AAP Policy Statement and Technical Report on Climate Change. These were published in 2015. (AAP Council on Environmental Health. "Global Climate Change and Children's Health." *Pediatrics* 136.5 (2015): 992 and Ahdoot, S, and Pacheco, SE. "Global climate change and children's health." *Pediatrics* 136.5 (2015): e1468-e1484.)

In 2014, I was hired as a consultant to the AAP to serve as the Medical Director of the Pediatric Environmental Health Unit program for the Eastern part of the U.S. I am responsible for providing oversight of the day-to-day operations of the units in Federal Regions 1-5; and, working with others, coordinate the management of all 10 units in the U.S.

In 2015, I created the Climate Change Initiative within the AAP, and was hired as a consultant to the AAP as Medical Director of that Initiative. Through our work, internal AAP stakeholders recognize that climate change is an issue for all components of the AAP, not just the COEH and the Climate Change Initiative. We have developed educational materials for pediatricians and for parents related to climate change.

Beyond the AAP, I have been instrumental in creating the Medical Society Consortium on Climate and Health (https://medsocietiesforclimatehealth.org/). The Consortium brings together 20 societies representing over 500,000 members to convey the messages that climate change causes health problems and that decreasing the use of fossil fuels and increasing energy efficiency and the use of clean energy sources will ameliorate these problems. The Consortium advocates at the Federal level on these issues.

In Virginia, I have worked with others to create Virginia Clinicians for Climate Action (VCCA) (https://states.ms2ch.org/va/) which is focused on the important relationship our changing climate has on health. VCCA advocates at the state level on these issues.

I have received various honors and awards, including, but not limited to: 2017 – Carol Strobel Memorial Award for Children's Environmental Health Advocacy, Children's Environmental Health Network; 2017 – John Rosen Memorial Lecture, Montefiore Medical Center, Albert Einstein College of Medicine; 2014 – Elected a Fellow of the Collegium Ramazzini, an international environmental and occupational health honorary society; 2014 – received the National Healthy Schools Hero Award from the Healthy Schools Network, 2013 – selected for the 11th Annual George J. Ginandes, M.D. Visiting Lectureship in Pediatrics at Mount Sinai School of Medicine, New York, NY; 2011 – Elected to the American Pediatric Society, a national honorary society.

Additionally, I have written extensively and lectured widely in the U.S. and overseas on a variety of topics related to children's environmental health. Please see my curriculum vitae for details.

EXPERT OPINION

I. YOUTH ARE DISPROPORTIONALLY IMPACTED BY CLIMATE CHANGE AND RELATED ENVIRONMENTAL POLLUTION

A. Physiological Features and Development of Children Make Them More Vulnerable and Susceptible to Certain Impacts

Children are not little adults – parents know this, doctors know this, and both courts and legislatures treat them differently. Therefore, when it comes to assessing children's vulnerability to adverse health impacts one cannot just extrapolate from a known health response to climate related problems, such as heat or smoke, etc., in an adult and predict the correct response in children (Selevan et al., 2000). There are numerous reasons why children are uniquely vulnerable to the impacts of climate change and air pollution associated with fossil fuels – most noteworthy, their bodies are not fully developed or mature, including vital organs like their lungs and the brain. For the purpose of this report, when we say childhood, or children, we include individuals up to age 21 years of age. There is no firm definition of childhood or children. Administratively, childhood is sometimes defined to end at 18 or 21 years of age. In terms of brain maturation, however, some people would say the brain doesn't finally mature until the frontal lobes are fully mylenated, which doesn't occur until about 25.

Particularly when children are young, they breathe more air per unit time than adults. Therefore, if the air that they are breathing is polluted, they will breathe more of that pollution than an adult. Children also consume more food per unit of body weight and likewise drink more water per unit of body weight. Therefore, if that food or water contains an environmental contaminant, then the child will get higher doses of that contaminant (EPA, 2008). Some of the body's organs that metabolize environmental toxicants, such as the kidneys and the liver, are not fully developed and do not yet have the enzyme systems necessary for these processes (EPA, 2013).

The body will respond to stressors differently at different ages. For example, while the exposure to excess heat may injure a child in utero or cause a miscarriage; the response would be very different in an 8-year-old child. We are very concerned, and the literature indicates, that infants and adolescents are at the greasiest risk from heat injury. The reason why children are at greater risk is because their bodies don't adjust to changes in heat as fast as adults. They don't sweat as much and produce more body heat than adults when they are active. Because children do not have the decision making capacity to protect themselves, they are also more likely to not drink enough fluids or rest enough when they are playing sports or engaged in other outdoors activities, and therefore are more likely to become dehydrated. Infants can't even communicate their discomfort or distress when they are overheating. Again, this is a situation where very young children literally cannot remove themselves from harms way. Adolescents, particularly young athletes not only cannot recognize the signs of heat injury, they are incentivized and pressured to continue to play, even at their own peril.

Another reason children are more vulnerable is because they spend more time outside than adults. Ideally children should be outside in nature, playing, getting exercise, and learning. However, if the temperatures are high or the air they breathe outside is contaminated with particulate matter, ozone, carbon monoxide, or other harmful air contaminants, the child's health will be harmed by being outdoors (Sheffield & Landrigan, 2011; Seal & Vasudevan, 2011; National Research Council, 1993). In our expert opinion, the Plaintiffs in this case are at risk of having decreased lung function as a result of growing up in environments with more air pollution, as are all of their similarly situated peers, a risk that adults do not face in the same way because their lungs are already fully developed.

The fact that children's immune systems are still developing also increase their vulnerability, especially when it comes to infectious diseases, a fact that the Environmental Protection Agency has acknowledged (EPA, 2013). Children less than five years old, both in industrialized and developing countries, absorb the majority, an estimated 88%, of the existing global burden of disease attributable to climate change (Zhang et al., 2007). Children in the world's poorest regions, where the disease burden is already disproportionately high, are most affected by climate change (Haines et al., 2006).

Moreover, and of particular importance in dangerous situations such as hurricanes, flooding, or wildfires, when important decisions, like whether or not to evacuate or where to seek safe shelter, need to be made, children are dependent on adults for their safety. Children do not have the maturity or the information on which to make decisions as to what to do in these situations. For the Plaintiffs involved in this suit, and for all children, they need the government, to protect the environment so that dangerous situations do not occur, are less severe or less frequent. The government has failed the children in this fashion, and indeed, by ignoring or acting contrary to the knowledge it has had, the government has acted to make the dangers posed by climate change even more extreme.

Children's inability to make decisions related to their own safety and other matters, is a reflection of brain maturation. Put simply, the brains of young children and adolescents are different from adults. In particular, the changes in brain development from in-utero through adolescence mark children as distinctly different from adults. "Indeed, much of the potential and many of the vulnerabilities of the brain might, in part, depend on the first two decades of life" (Toga et al., 2006). As a result of non-invasive techniques, such as functional magnetic resonance imaging (MRI) we can actually see the very fibers of the brain and better understand the anatomical differences in adolescent brains. Brain imaging technology has shown that regions of the adolescent brain are not mature until after age 18.

The brain of the newborn is one-quarter to one-third of its adult volume and consists of an estimated 100 billion neurons and supporting glial cells at birth. As the brain matures, the neurons become wrapped in a myelin sheath that increases the velocity of message transmission between neurons. Myelination of the regions of the brain responsible for higher cognitive functions is an ongoing process during child development and continues well into adolescence (Sowell et al., 2004). Synapses are the place where neurons connect for the transmission of messages from one neuron to the other. In general, the number of synapses increases as the brain develops. "The first areas [of the brain] to mature were those with the most basic functions, such as those processing the senses and movement. Areas involved in spatial orientation and language (parietal lobes) followed, around the age of puberty (11–13 years). Areas with more advanced functions – integrating information from the senses, reasoning and other 'executive' functions (e.g. prefrontal cortex) – matured last, in late adolescence." (Toga et al., 2006). Over time, in repeated MRI scans on children developing in a typical fashion, changes in the thickness of the cerebral cortex correlated with changes in cognition as the child ages (Toga et al., 2006). Adolescents' cognitive differences become especially pronounced when emotions such as stress are present.

Exposure to air pollution affects neuron development, myelination and synapse integrity, halting the development of a healthy brain in children. It is thought that air pollutants in exposed children reach the brain via a disrupted nasal epithelium or the blood brain barrier. The ensuing immune activation generates a systemic and neuroinflammatory response that promotes brain tissue injury, demyelination and decreased synaptic activity. These injured areas, composed of demyelinated neurons with reduced blood flow, appear as white matter hyperintensities (WMH) on MRI studies. Among affected brain areas are the prefrontal and frontal cortex, vital for normal cognition. White matter hyperintensities are found in the brains of children living in areas of high air pollution and are associated to cognitive deficits (Brockmeyer, 2016).

To summarize, some of the key differences between children and adults are:

1. Children have larger body surface area compared to adults. This increases the risk of fluid and heat loss.
2. Children have a higher respiratory rate with higher minute ventilation and entry of polluted air to the lungs.
3. Lung growth and development continues through childhood so the respiratory system of children may be more susceptible to environmental-related injuries and may be altered by environmental exposures.
4. Children's immune system is immature before age 2 years.
5. Children have higher metabolic demands. They require more calories and water per unit of body weight.
6. The central nervous system of children is not mature. Neurodevelopment continues through the second decade with continued changed in myelinization, synaptogenesis, etc. This means children are more susceptible to damage by neurotoxicants.

B. Many Health Issues Children Experience are Directly or Indirectly Related to Climate Change But Climate Change Goes Under-diagnosed as a Factor.

None of the medical issues currently related to climate change are being tracked by standard medical or pharmaceutical administrative databases. Unless something is changed in the way the data is coded and aggregated by the data systems, this will remain true for the foreseeable future. Therefore, we currently have no mechanism to accurately track the scope of medical problems that are linked to climate change. However, as discussed more below, there is abundant evidence that climate change is exacerbating health challenges for children, even if doctors aren't always making the direct connection to climate change. The lack of tracking means that the health impacts of climate change are likely being underestimated. The following are hypothetical, but realistic, scenarios, showing how the limitations of the coding systems means that information about the influence of climate on health is being, and will be, missed.

The International Classification of Diseases, 10th Revision, Clinical Modification, often abbreviated as ICD-10-CM is the system most commonly used in the U.S. to classify and code all diagnoses recorded in conjunction with all medical care in the United States. ICD-10-PCS is the system used to code procedures performed in in-patient settings. CPT codes are used by providers to report procedures and professional services in ambulatory settings.

For example, Jamisha is an 8-year-old from Cleveland who went on a camping trip in the woods with her Girl Scout troop. About 10 days later, she develops a halo-rash on her back. She sees her doctor who makes a diagnosis of Lyme Disease. The IDC-10-CM code for Lyme Disease is A69.20. There is no way to provide any additional coding to indicate that this is a diagnosis made in Ohio; and Ohio, absent climate change, is outside of the original range of the deer tick which bit Jamisha and transmitted the parasite that caused the Lyme disease.

Alex is a 10-year-old with known asthma. His father calls in a refill for his albuterol inhaler, a rescue as opposed to a maintenance medication. There is no way for the pharmaceutical database to code for that fact that Alex lives 50 miles down wind from a wildfire; and the air pollution from the wildfire is causing an exacerbation of his asthma.

Ms C is a 36-year old-woman who is pregnant with her 3rd child. Each of the prior pregnancies has been uncomplicated and the babes born at term. She is in her 36th week of pregnancy; and the ambient temperature has been 102 degrees F for the entire week. Nighttime lows are about 96 degrees. The family is low income and has a fan, but no air conditioner. The mother goes into labor and delivers a child. This child is considered premature. The baby's ICD-10-CM code would be p07.39. There are additional digits that can be added to indicate prematurity with or without major problems. The mother's diagnostic code would be ICD-10-CM diagnosis code o60.10x0. There are various other codes that could be used; but the point is that there are no codes or modifiers to indicate that this mother may have delivered a premature infant because of high ambient temperatures due to climate change in a setting where she has no access to air conditioning.

There are a number of other hypothetical cases that could be constructed around other diagnoses:

1. Gastroenteritis in children is more common when it rains a lot.
2. Gastroenteritis in children is more common when the ambient temperature goes up.
3. Asthma attacks are more common in warm weather.
4. Asthma attacks are more common when ambient ozone levels are higher (which may explain some, but not all, of 3).
5. The allergy season lasts longer in certain parts of the U.S.
6. Severe weather events result in more physical injury in children.
7. Infant, as well and teen-aged athletes (particularly football players), are more likely to have heat-related illness or injury the higher the temperature.
8. There are more children with mental health problems after severe weather events.

All of this information taken together indicates that the impact of climate change is occurring now and there is no way to systematically track the full magnitude of the impact. Unless the systems change, this problem will continue on into the future.

The Plaintiffs in this case have experienced some of the health issues enumerated above. The children of America have experienced all of the problems enumerated above. The federal government has been remiss in allowing the continued use of fossil fuels that have contributed to the greenhouse effect that is harming the planet and leading to excess health problems for children in the formative stages of their physical and emotional development.

C. Certain Categories of Children Are Especially Vulnerable to Climate Change Impacts and Air Pollution

The federal government has found that communities of color, immigrants, indigenous peoples, those living in coastal areas, those with preexisting or chronic medical conditions, and the economically disadvantaged are disproportionally vulnerable to public health threats due to climate change (Crimins A.J., et al., 2016; EPA Endangerment, 2009). Among other hurdles, these populations tend to have reduced access to resources to help deal with the impacts of climate change, such as air conditioning, health care, adequate shelter, and the financial means to relocate either permanently or temporarily should that become necessary. The children in these population groups face added vulnerabilities for the reasons explained above.

Children who live in coastal areas are on the frontlines of climate change due to sea level rise and flooding and are especially vulnerable. Sea level rise is a real problem today for many places in the U.S.; and will become a more severe problem going forward. Already, in Virginia, we have experienced an increase in nuisance flooding. Norfolk, VA has seen a 325% increase in nuisance flooding for the time frame of 2007-2013 compared to 1957-1963 (US Climate Resilience Toolkit). Today, Virginia has 164,000 people at risk of coastal flooding. By 2050, an additional 137,000 people are projected to be at risk due to sea level rise in Virginia (Climate Central). Norfolk Public Schools have collaborated with many other constituencies to create the "[Norfolk] Coastal Resilience Strategy (Norfolk Coastal Resilience Strategy). Children living in the low-lying coastal areas along the Gulf of Mexico, or just barely above sea level along Florida's coast, and other sea level rise prone areas in the U.S. already are, and will continue to experience a significant burden on their health from rising seas and higher storm surges. This flooding, whether associated with severe weather events or nuisance flooding associated with low-lying land and the vagaries of the tides, can be an Adverse Childhood event for the Plaintiffs and similarly situated children in the U.S. The need to leave a home, to have a school shutdown, to lose accessibility to a playing field or other recreational activities has a profound adverse impact on children. It affects their mental health leading to depression, anxiety and post-traumatic stress disorder. Moreover, it puts these children at risk for long-term health problems, myocardial infarction diabetes, etc. in adulthood (Balaban, 2006).

Several of the Plaintiffs in this case live in areas making them especially vulnerable to sea level rise. For example, Levi D.'s home is about a mile from the Atlantic Ocean and is just about at sea level (Declaration of Levi D. at ¶¶ 1, 2). Without immediate actions to reduce greenhouse gas emissions, scientists expect the ocean to be at his doorstep in the coming decades (Declaration of Levi D. at ¶ 3). Miko V.'s fear that she will not be able to travel back to her home of origin in the Marshall Islands because they will be submerged by sea level rise is an appropriate response of an adolescent child who understands the ramifications of climate change (First Amended Complaint at ¶ 57). There are a number of reports, both in the scientific literature and the popular literature about the inundation of the Marshall Islands, the Seychelles Islands, low lying parts of Bangladesh and elsewhere (Webb & Kench 2010). The dynamic response of reef islands to sea-level rise: evidence from multi-decadal analysis of island change in the Central Pacific (Davenport, 2015). These impacts of sea level rise on children's lives, while they are still developing, are psychologically significant and adverse.

It is also widely recognized that some populations, including poor populations and minority populations are also more likely to be located close to sources of environmental pollution, and accordingly, children from those communities are more vulnerable. It is not uncommon for these communities to be located next to petroleum plants, waste dumps or incinerators, high-traffic areas, hazardous waste sites and other sources of pollution (Rubin et al., 2013). Children, and their families, living in these types of situations experience psycho-social stress that may account for the decreased health status of the individuals in these communities (Gee & Payne-Sturges, 2004).

It is our expert opinion that the exigencies of climate change only add to the stress on the children in these low-income communities or communities of color or communities already exposed to multiple environmental health hazards and air pollutants. This is true for some of the Plaintiffs in this case and any similarly situated children in the U.S.

II. SPECIFIC WAYS YOUTH ARE IMPACTED BY CLIMATE CHANGE

As described in more detail below, climate change is currently affecting child health through increased heat stress, decreased air quality, altered disease patterns of some climate-sensitive infections, physical and mental health effects of extreme weather events, and food insecurity in vulnerable regions (see **Figure 1**). At present, the global health burden attributable to climate change is poorly quantified compared with other health stressors (IPCC, 2014). As we describe above, in our expert opinion, the lack of reporting for climate related health issues and diagnoses likely leads to an underestimate of the true impact of climate change on children's health.

A. Increased Heat Stress and Other Temperature Effects

In a business as usual scenario the frequency of hot days and heat waves will continue to increase. The federal government has stated that "increasing concentrations of greenhouse gases lead to an increase on both average and extreme temperatures" (Crimins et al., 2016). The devastating effect of heat waves is exemplified by the July 1995 Chicago heat wave that resulted in over 650 deaths in a period of 5 days (CDC, Extreme Heat). An even more sobering example is the 2003 Europe heat wave, which caused over 70,000 additional deaths (Robine et al., 2008). It is expected that climate change-related heat waves will overtake natural variability as the primary cause of heat waves in the western United States by the late 2020s and by the mid-2030s in the Great Lakes region. The same changes are expected in the northern and southern Plains in the 2050s and 2070s, respectively (Lopez et al., 2018).

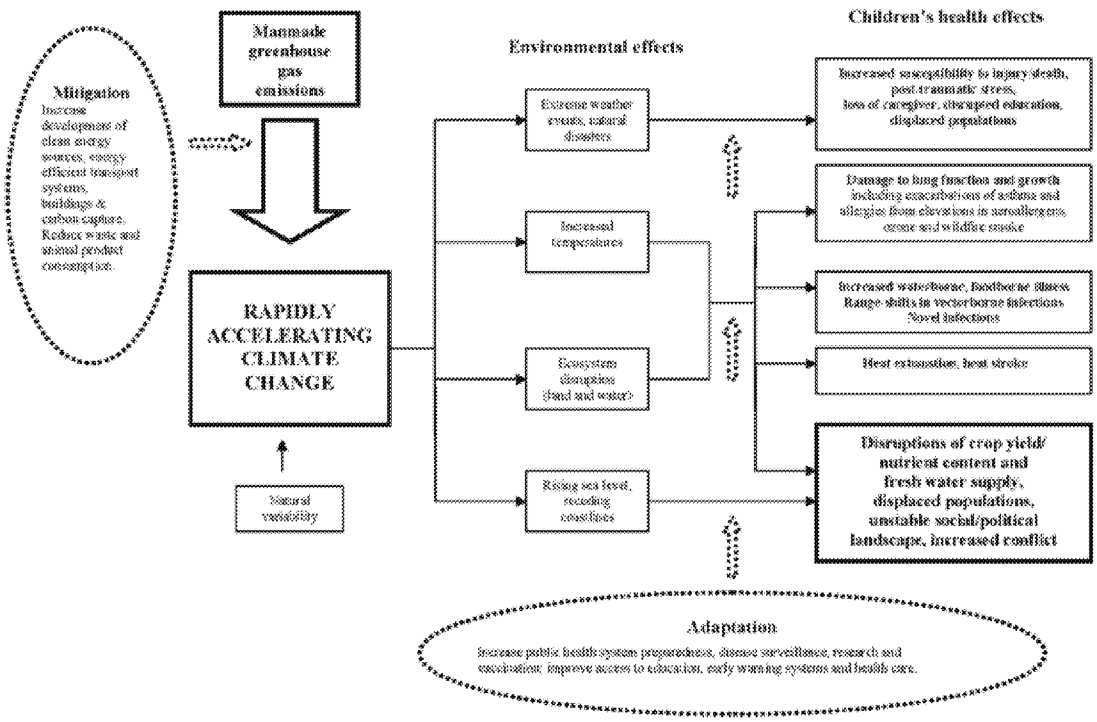

Figure 1: Potential effects of global climate change on child health. Adapted from American Academy of Pediatrics policy statement "Global Climate Change and Children's Health" (Shea, 2007).

Extreme heat is one of the leading causes of environmental deaths in the U.S. According to the EPA, over the past three decades, nearly 8,000 Americans were reported to have died as a direct result of heat-related illnesses (EPA, 2014). As the temperature continues to rise due to unmitigated climate change, the morbidity and mortality associated with heat waves are expected to increase. This problem is compounded by the heat island effect resulting in daytime temperatures 0.9°–7.2°F (0.5°–4.0°C) higher and nighttime temperatures 1.8°– 4.5°F (1.0°–2.5°C) higher in urban areas compared to rural areas (Wuebbles et al., 2017). These temperature variations are alarming considering that in 2010 over 80.7% of the U.S. population lives in urban areas (U.S. Census Bureau)

Children have a higher risk of dying, and are among those most vulnerable to health problems, from excess heat. Public health studies have concluded that children under 15 are more likely to die from excess heat than adults, and children under five are particularly at risk (Zivin & Shrader, 2016). Research has found that for every increase in temperature of 1°C (1.8°F) above a temperature threshold of between 27°C (80.6°F) to 29°C (84.2°F) adults experience a 2-3 percent increase in mortality. The mortality rate for children is between 50-100 percent higher (Zivin & Shrader, 2016). The federal government has found, with a "very high confidence," that children face a higher risk of getting sick or dying from extreme heat (Crimins et al., 2016).

The vulnerability of children to extreme heat is multifactorial and results from their different physiologic, metabolic, behavioral characteristics and dependence in others to take care of them, as well as the fact that they tend to spend more time outside than adults (Xu et al., 2014b). Obese children, children with chronic diseases such as kidney disease, metabolic and respiratory diseases and neurologic conditions are more susceptible to heat-related illness. Although older adults comprise the most numerically affected group during heat waves, neonates, children less than one year of age or in the 0-4 age group are more vulnerable to heat-related morbidity and mortality (Basagaña et al., 2011; Basu et al., 2008; Xu et al., 2012; Xu et al. 2014a; Xu et al. 2014b). High heat has been linked to sudden infant death syndrome and evidence from heat waves shows that the leading causes of deaths for infants are cardiovascular illness, blood disorders, and failures of the digestive system (Zivin & Shrader, 2016). When one compares the heat-related vs. cold-related death rate for infants, higher rates of heat vs. cold-related mortality are observed, with a death rate of 4.2 vs. 1.0 deaths per million respectively (Berko, 2014). In the 2006 California heat wave ER visits in 58 counties in California in July and August were increased for all ages, but the effects were more significant in the 0-4 years age group (Knowlton et al., 2009).

Heat illness during outdoor sports is a leading cause of death and disability, with an average national estimate of 9,237 illnesses annually. A high risk group for heat-related exhaustion and stroke is high school athletes (CDC, 2010). According to the 2010 report by the American Football Coaches Association, from 1960 through 2009 there were 123 fatal heat stroke cases (Mueller & Colgate, 2010). In addition to the inevitable exposure to high heat, their competitiveness and group pressure makes them ignore early signs of heat-related illness making them more vulnerable to heat-related morbidity and mortality. Another high risk group for heat related illness is the hundreds of thousands of child farm laborers in the U.S., who are often exposed to scorching heat without adequate acclimatization or preventive measures to avoid heat-related illness.

The damage inflicted by the increase in environmental temperature resulting from climate change goes beyond the associated morbidity and mortality described in the previous section. Increasing temperatures will affect the physical, emotional, and cognitive development of children. Unfortunately, healthy child activities such as playing outdoors will continue to be replaced by safer but not necessarily better options. The substitution of outdoor play activities by indoor play spaces or use of entertaining electronic devices is not an unusual scenario in the U.S. The ensuing sedentary life affects children in different ways. For obese children, the lack of participation in outdoor activities contributes to the complex dynamics leading to obesity. I (Dr. Pacheco) have patients with chronic conditions that wear cooling vests, similar to those used by outdoor workers, to be able to participate in outdoor activities such as going to the zoo on a hot day. In our expert opinion, this is not a healthy lifestyle for a child and certainly not a common practice for children fifty years ago; instead it is in direct response to increasing extreme temperature conditions. As pediatricians we don't have a good reply for Jaime, one of the Plaintiffs, when she says "I have been negatively affected by the increasing temperatures, which limits the time I'm able to safely spend time outdoors" (Declaration of Jaime B. at ¶ 7). We cannot advise her to play indoors, get used to it, or wear a cooling vest. Worst of all, with the current projections for temperature increase in the U.S., we cannot tell her that it will get better in the foreseeable future and that her physical and mental health will not be affected.

Children's learning is also affected by hot temperatures and heat waves. It is not hard to imagine how difficult it is to work in a classroom without air conditioning during a very hot day. Classroom temperature and ventilation is known to affect school performance (Wargoki & Wyon, 2007. During the September 2017 heat wave, the Elementary Teachers Federation of Ontario expressed their concern about how working in classrooms without air conditioning systems was insupportable and affected children's learning (Loriggio, 2017). There is also evidence linking heat waves and above average temperatures to an increase in violence and abuse as well as depression (Rinderu et al., 2018; Majeed & Lee, 2017).

In our expert opinion, extreme temperatures and other heat-related impacts especially harm children in different ways from adults due to the unique physiology and lifestyle of children.

B. Extreme Weather Events

i. Hurricanes, Heavy Precipitation Events, and Flooding

As a result of climate change, the frequency and severity of extreme weather events, such as hurricanes and floods, are predicted to continue to increase (Crimins et al., 2016). The federal government has stated with a "high confidence" that children living in coastal areas will be especially vulnerable due to flooding from an increase in extreme precipitation, hurricane intensity, as well as sea level rise and the related increase in storm surge (Crimins et al., 2016). Children are especially vulnerable because they rely on others for their safety and well-being, and their caregivers can often be unprepared or overwhelmed. Floodwaters are often contained with toxic chemicals, raw sewage, and other pollutants that make children ill. Adverse health impacts can include infectious, respiratory, and skin diseases, and increased risk of gastrointestinal illness due to exposure to pathogens like Cryptosporidium and Giardia (EPA, 2009). While for adults, the impacts of gastrointestinal diseases are often mild, for children, the impacts can be much more severe, and even fatal (EPA, 2008). Hurricanes and other extreme weather events are also linked to an increased risk of death and other injuries.

In the aftermath of extreme weather events, there are often persistent health impacts associated with malnutrition from disruptions in food supply, diarrheal illness from contaminated water, and limited or no access to medical care. Such disasters can also result in significant psychological harms for children who experience the loss of their home, possession, or pets; witness other people experience such losses; suffer grief and stress from the loss of loved ones or from seeing their parents undergo stress; and have their social support networks – such as school, friends, family, or church – destroyed, either temporarily or permanently (Kousky, 2016). Children who are exposed to such traumatic events, often experience long-lasting impacts, especially if in the aftermath there is reduced attention and investment in the child's health and education or if the disaster occurs at a critical point in the child's development. The impacts can be life-long, and even impact the next generation.

To make matters even worse, water-damaged homes are also often impacted by mold and mycotoxins which can cause respiratory problems for people when they move back into their water-damaged homes (Hope, 2013). Exposure to mold and mold components has been known to trigger inflammation, asthma, autoimmune disorders, and immune suppression, among other adverse health impacts.

Puerto Rico's experience with Hurricane Maria is just a window to the world that our generation is leaving for Plaintiffs like Levi, Jayden, Victoria, as well as other children living in the paths of extreme weather events like hurricanes. In a business as usual scenario and with unmitigated climate change, extreme weather events such as Hurricane Maria will occur with increased frequency.

When Hurricane Maria made landfall in Puerto Rico in September, 2017, no one could imagine the devastation the hurricane would cause. Maria struck Puerto Rico as a category 4 hurricane, with wind gusts above 175 mph. The day after the hurricane 3.4 million Puerto Ricans, including ~ 700,000 children, woke up to a destroyed island without access to power, clean water, gasoline or fresh food. A month after the disaster there were still 3 million Puerto Ricans without electricity and one million without access to clean water. As of March of 2018, 10% of electricity customers were still without power. The number of total deaths above average in September, October, and November was 1,230.

From September to late December 2017, nearly 300,000 Puerto Ricans emigrated to the mainland; most of them (270,000) to Central Florida. Most of the people leaving the Island are families with children which has caused schools closures in many towns. Approximately 467 schools are expected to close by 2022 as a result of Maria. Florida school districts have enrolled more than 11,200 displaced students from Puerto Rico and the Virgin Islands. According to Save the Children "Half a year since Hurricane Maria struck Puerto Rico, school-age children have collectively missed out on more than 13 million full days of learning. Many schools are only operating on a limited daily schedule, from 7:30 a.m. to 12:30 p.m., due to electricity, water and sewage problems." (Save the Children, 2018).

The potential negative effect that the departure to the mainland imposes to their cultural heritage is a source of anguish for many Puerto Ricans who want their children to value their roots. There is a sense of pride about living in an island with a strong sense of identity and resilience, historical monuments, unique fauna and lush vegetation. Without immediate actions by the federal government to address climate change, in our expert opinion, the number of children experiencing significant health impacts from extreme weather events will continue to grow.

ii. Wildfires

As a result of climate change, the wildfire season is becoming longer and wildfires are more widespread, severe, and destructive. The effect of wildfires on children is expected to worsen as wildfires in some areas of the U.S. are expected to increase with unmitigated climate change (Abatzoglou & Williams, 2016). Of the many compounds present in the smoke of wildfires PM, CO, and O_3 seem to be most damaging to children's health. Children, and especially children with asthma, are among those most at risk from exposure to PM. The EPA has found that PM from wildfire "can contribute to acute and chronic illnesses of the respiratory system, particularly in children, including pneumonia, upper respiratory diseases, asthma and chronic obstructive pulmonary disease" (EPA, 2009). Many of the compounds in wildfire smoke are strong irritants of the respiratory tract triggering asthma exacerbations and affecting other respiratory conditions. In the 2003 southern California wildfire, exposed children had mainly complaints relating to the eyes, and upper and lower respiratory tracts (Künzli et al., 2006). During the same wildfire season Delfino et al., found an association between PM2.5 exposure and increased asthma hospital admissions for the elderly and children age 0-4. Post-fire hospital admissions for pneumonia, bronchitis and bronchiolitis also increased. Although hospital admissions for 5-18-year-old children also increased, these were not specifically associated to PM2.5 (Delfino et al., 2009). The Plaintiffs in this case are already having their health impacted by wildfires. As Sahara V. noted in her declaration, "I have asthma, and the increased frequency of forest fires in Oregon, due to hotter and drier conditions, has triggered asthma attacks for me. The smoke inhibits my ability to breathe, causes my throat to close up and causes me to use my inhaler often" (Declaration of Sahara at ¶ 4). During the 2017 summer, Jacob Lebel was forced to work on his family farm in thick smoke that prompted air quality alerts by the Oregon DEQ (Declaration of Jacob Lebel at ¶ 9). For both Jacob, Sahara, and other Plaintiffs exposed to smoke from wildfire, we would expect, consistent with the literature, that their increased exposure to smoke with more common and more severe wildfires to exacerbate existing health issues, such as asthma, and may cause new acute and chronic respiratory illnesses.

C. Decreased Air Quality Leading to Asthma and Allergies

There is evidence that climate change is affecting the distribution, allergenicity, seasonality and pollen production in different parts of the country as well as globally. The federal government has found with "high confidence" that "[c]hanges in climate, specifically rising temperatures, altered precipitation patterns, and increasing concentrations of atmospheric carbon dioxide, are expected to contribute to increases in the levels of some airborne allergens and associate increases in asthma episodes and other allergic illnesses" (Crimins et al., 2016). Climate change is leading to warmer spring temperatures, which means plants start producing pollen earlier, warmer fall temperatures, which extend the growing season for plants like ragweed, and increased pollen production per plant due to increased CO_2 (EPA, 2014; Crimins et al., 2016). This in turn can lead to increased allergen sensitization in susceptible individuals. Longer pollen seasons have been described for weeds such as ragweed (Ziska et al., 2011), and earlier flowering seasons have been reported for other pollens such as grass, birch, weeds (i.e., mugwort) and the olive tree (Bielory et al., 2012). Although the total pollen protein concentration remains stable, the ragweed allergen Amb a 1 concentrations increase with increasing CO_2 levels (Singer et al., 2005). The longer flowering seasons can translate to increased allergen sensitization, increased morbidity for allergic individuals, and an increase in asthma or asthma exacerbation in susceptible individuals. Elevated pollen counts have been associated with increased emergency room visits in children and adolescents with asthma (Darrow et al., 2012, Erbas et al., 2018).

The combination of exposure to allergens and different air pollutants can increase allergic sensitization, allergic symptoms, and asthma in children and adolescents (Riedl, 2008). For example, the incidence of asthma increases by exposure to allergens and other pollutants, such as diesel exhaust products (Gilmour et al., 2006). Taken together there is a complex interplay between the individuals' characteristics, atopic disease, aeroallergen and air pollutants exposure and time of exposure that may facilitate and potentiate the development of asthma in susceptible individuals. According to a report by the federal government, there are roughly 6.8 million children in the U.S. impacted by asthma "making it a major chronic disease of childhood" (Crimins et al., 2016). Minorities and economically disadvantaged children are disproportionally impacted. Again, according to a federal government report, "[i]n 2007-2010, the percentages of Black non-Hispanic children and children of 'All Other Races' reported to currently have asthma, 16.0% and 12.4% respectively, were greater than for White non-Hispanic children (8.2%), Hispanic children (7.9%), and Asian non-Hispanic children (6.8%)" (Crimins et al., 2016). Several of the Plaintiffs in this case have asthma and allergies, including Jaime B., Sahara V., Levi D., and Nathan B. (First Amended Complaint at ¶¶ 46, 67, 75, 85). We would expect that the number of children with asthma and allergies will increase, and those who already have asthma or allergies, will experience more severe health impacts as a result of climate change.

D. Infectious Disease Patterns Changing

Climate change is expanding and shifting the range and habitat of disease-carrying organisms, such as mosquitos, ticks, and rodents, and as a result, exposing more people to diseases such as Lyme disease, West Nile virus, and Dengue fever (EPA, 2013). Because children tend to spend more time outside and don't have fully developed immune systems, they are more vulnerable and more likely to contact disease-carrying organisms (EPA, 2013). The EPA has reported that "[t]he incidence of Lyme disease in the United States has approximately doubled since 1991, from 3.74 reported cases per 100,000 people to 7.01 reported cases per 100,000 people in 2012" (EPA, 2014). In our expert opinion, an increasing number of children will experience adverse health impacts as infectious disease patterns continue to change.

E. Food, Water, and Nutrient Insecurity, Scarcity, and Toxicity

Climate change, resulting from increasing CO_2 levels, is changing the way plants grow and will lead to food insecurity on a global scale and, in the long-run this will put American children at risk. By taking active steps to decrease CO_2 levels now, we can decrease the severity of this problem in the future.

On the one hand CO_2 can increase the growth of plants. However increasing atmospheric CO_2 leads to lower protein content of the edible portions of wheat, rice and barley (Taub et al., 2008). Similarly, wheat, rice, soybeans, and field peas grown at higher CO_2 levels have been shown to have lower concentrations of zinc and iron (Myers et al., 2014). These changes in the nutrition value of basic food stuffs for billions of people across the globe pose grave risk for infant malnutrition with death in some and stunting in many others (Högy & Fangmeier, 2008; Högy et al., 2009).

There are a number of other factors related to climate change that will impact agriculture and the availability and quality of food to feed the world's children. Extreme heat decreases the growth of plants. Water is likely to be less available for irrigation and animals as it will be needed for human use. This will decrease plant and livestock production. Severe weather events, including drought and flooding, not only impact human health directly as noted elsewhere in this report, they also limit the growth of crops or can destroy them in the field and orchard. Sea level rise can inundate and destroy farmland directly or, through salinification of groundwater, making it impossible to grow crops. Unless, and until, the nation reduces CO_2 pollution and other anthropogenic greenhouse gases, there is a real increasing risk of malnutrition and death in children (Cohen et al., 2008; Lake et al., 2012; Miraglia et al., 2009; Hatfield et al., 2011; Battisti & Naylor, 2009; Asseng et al., 2011)

Changes in marine ecosystems, such as, warming of the ocean's upper layers, ocean acidification, and declining oxygen concentrations in the oceans, are leading to the risk of decreased seafood availability and safety. Because so many population groups around the world depend on seafood for their source of protein, changes here only increase the risk of malnutrition leading to death or stunting.

Several of the Plaintiffs have expressed concerns about the changes in the oceans affecting their ability to adequately maintain seafood in their diet: Miko V., Kiran Oommenn, Zealand B., Aij P., Hazel V., and Avery M. In our expert opinion their concerns are well-founded. There is strong scientific evidence that the oceans are changing as a result of climate change; and those changes are putting the availability and safety of seafood at risk.

According to the EPA, "considering the trend over near- and long-term future conditions, the Administrator finds that the body of evidence points towards increasing risk of net adverse impacts on U.S. food production and agriculture, with the potential for significant disruptions and crop failure in the future." (EPA Endangerment, 2009). We agree and in our expert opinion, children will be adversely impacted by food, water, and nutrient insecurity, scarcity, and toxicity.

F. Decreased Water Quality and Algal Blooms

Algae are a normal component of aquatic ecosystems. These are plant-like organisms that are multi-celled or single-celled and photosynthetic. Harmful algal blooms (HABs) occur when colonies of algae along seacoasts or in fresh water bodies proliferate, and produce toxic effects on people, pets, aquatic species, and birds. While the causes of HABs are complex, growing evidence suggests that climate change contributes to these events – algae blooms are more likely to occur in warmer waters, and waters are warming due to climate change (Gobler et al., 2017; O'Neil et al., 2012; Havens & Paerl 2015). The toxic effects of HABs can occur when the algae are consumed or, sometimes, just from skin contact. The symptoms of contact with HABs range from diarrhea to respiratory illness to neurotoxicity, and may even be fatal (Otten & Paerl 2015; Berdalet et al., 2015). Children are at specific risk from HABs because they are different from adults (Weirich & Miller, 2014). They have a smaller body size. Therefore, ingestion of fish or shellfish or drinking water contaminated by HABs delivers a greater dose of the toxin to the child than an adult. Children less able to make decisions to protect themselves from harm and may play in or drink contaminated water when an adult would not do so. Specific Plaintiffs have already been affected by algae blooms and other water quality issues linked to climate change. For example, unprecedented algae blooms have closed and delayed the opening of the Dungeness crabbing season in Oregon and lead to restriction on mussel harvesting, which has limited the ability for Jacob to consume shellfish, an important part of his food supply, as well as recreational activities (Declaration of Jacob Lebel at ¶¶ 18, 20). Journey Z. can no longer swim in the Hanalei River in Hawaii because of dangerous bacteria levels that made him sick last time he swam there (Declaration of Journey Z. at ¶ 16). Levi D. can no longer swim in the Indian River Lagoon due to flesh-eating bacteria and his ability to swim in the Atlantic Ocean has been limited for the same reason (First Amended Complaint at ¶ 83).

In our expert opinion, children are disproportionately impacted by decreased water quality and algae blooms as a result of climate change.

III. CHILDREN ARE ADVERSELY IMPACTED BY AIR POLLUTION FROM FOSSIL FUELS

In addition to children being harmed by climate change in ways that are different from how adults are harmed, children are also harmed by the air pollution issues from the extraction and burning of fossil fuels, which lead to climate change. Thus, the fossil fuel energy system of the nation has collateral adverse impacts on the health of children, in addition to climate change and sometimes those harms are synergistic, like in the case of children's respiratory health and ozone.

The extraction and burning of fossil fuels, the primary driver of climate change, accounts for most of the airborne particulate pollution, which has a detrimental effect on air quality. Burning fossil fuels releases many chemicals and particulates to the air. These include fine particulate matter, black carbon, polycyclic aromatic hydrocarbons (PAHs), mercury, lead, oxides of nitrogen, sulfur dioxide, and carbon monoxide. In October of 2013, the International Agency for Research on Cancer (IARC) classified air pollution as a human carcinogen. Out of the six criteria pollutants monitored in the U.S., four are the main culprits of respiratory disease exacerbation during days of poor air quality (ground level ozone (O_3), sulfur dioxide (SO_2), particulate matter (PM), and nitrogen dioxide (NO_2)). Of these, ozone and PM have been associated with higher morbidity and mortality in vulnerable groups, such as children.

Ozone is formed when oxides of nitrogen, which can come from diesel exhaust, and VOCs interact with sunlight. Ground level ozone is an irritant to the lungs and is known to worsen with climate change and increased temperatures. Some of the health effects that are associated with ozone are: shortness of breath, coughing, and aggravation of chronic lung diseases such as asthma, chronic obstructive pulmonary disease (COPD), which is also known as emphysema. Damage to the lungs continues even when symptoms have dissipated. Exposure to ozone during childhood not only exacerbates asthma, but also can lead to new on-set of asthma as well as permanently impacting lung function (Searing & Rabinovitch, 2001). While everyone loses some of their lung function as they age, children with lesser lung function may be more likely to develop chronic lung diseases as adults.

PM is a complex mixture of solid and liquid particles released into the atmosphere when fossil fuels and other materials are burned or during wildfires. Particles of 2.5 micrometers or less (PM2.5) can enter the lung and reach the alveoli and from there the circulation.

In general, exposure to air pollutants can trigger airway inflammation and hyper-responsiveness and decrements in lung function (Koren, 1995; Seltzer et al., 1986; Silverman et al., 2010). Air pollution can lead to new cases of asthma, aggregate existing asthma, decrease lung functioning, increase respiratory symptoms like coughing, and lead to other adverse health impacts for children. Children with chronic health conditions such as asthma, aeroallergies, cardiovascular disease, cerebrovascular disease, or chronic lung diseases are more susceptible to poor air quality – visits to the emergency room (ER) and hospital admissions are more common during poor air quality days. Although some air quality conditions have improved since the implementation of the Clean Air Act, more than four in ten people in the U.S. (38.9%) live in communities with poor air quality (American Lung Association, 2017). Children from low income populations, both in the United States and globally are disproportionally exposed and affected by polluted air.

Children are particularly vulnerable to outdoor air pollution as they spend more time outdoors, have higher minute ventilation, and inhale more pollutants per pound of body weight (Gilliland et al., 1999; Dixon, 2002). Increased respiratory symptoms, such as asthma exacerbations, wheezing and cough, transient or permanent decrements in lung function and upper airway infections have been associated with exposure to air pollution in the pediatric population (Nicola, 1999; MacIntyre et al., 2014; Esposito et al., 2014). Asthma is the most common pediatric chronic disease, affecting 6.8 million, or 9.3% of American children in 2012 (Bloom et al., 2013). In 2008, asthma accounted for an estimated 14.4 million lost days of school among children in the U.S. (Meng et al., 2012). Early exposure to air pollution has been associated with the development of asthma in children. McConnell et al. followed a cohort of children less than 6 years and monitored the development of new-onset asthma in association to exposure to traffic-related air pollution (TRAP). They found that new onset asthma was associated with exposure to non-freeway traffic-related pollution at homes and schools, with rates higher in children with a history of allergy, parental history of asthma and maternal smoking during pregnancy (McConnell et al., 2010). A longitudinal birth cohort study assessed the incidence of asthma from follow-up visits up to 14-16 years in the context of exposure to NO_2 and PM2.5 at the birth address. It was found that exposure to NO_2 and PM2.5 at the birth address was associated to the incidence and prevalence of asthma throughout childhood and adolescence (Gehring et al., 2015).

Asthmatic patients have more emergency room visits and hospitalizations in days with poor air quality. Hospital admissions in three cities in Texas increased in children ages 5-14 after short-term exposure to elevated ozone (Goodman et al., 2017). Besides, increased pediatric ER department visits for asthma exacerbations have been associated with elevated ozone and PM10 levels (Tolbert et al., 2000). A retrospective study by Silverman et al., examined the risk of intensive care and general hospital admissions for patients of all ages in 78 hospitals in New York admitted to the hospital from 1999 – 2006, at times of elevated ozone and PM2.5. For both ozone and PM2.5 exposures, children ages 6 – 18 years had an increased rate of ICU admissions and general hospitalizations associated to high levels of PM2.5 and ozone (Silverman & Ito, 2010).

In my practice I, Dr. Susan Pacheco, have seen children whose asthma has been under excellent control for a long time, present with an unexplained asthma exacerbation in spite of strict compliance with medical recommendations and no identifiable triggers. In these patients, I, Dr.

Susan Pacheco, have invariably found that the days preceding their exacerbations were days with poor air quality. To this effect many of the parents of children with asthma, and at times their own children (one as young as five years), monitor the air quality index to decide if they will participate in outdoor activities.

In addition to patients with asthma, other patient populations can be adversely affected by exposure to air pollution. In patients with cystic fibrosis, air pollution exposure can cause a functional decline in lung function and increased pulmonary exacerbations (Goss et al., 2004). This has been observed upon exposure to PM10, NO_2, and ozone (Goeminne et al., 2013). In addition, the mean annual concentration of PM2.5 in the calendar year prior to birth is an independent risk factor for MRSA and Pseudomonas acquisition (Psoter et al., 2017; Psoter et al., 2015). Children with sickle cell disease are vulnerable to complications in days of poor air quality. Exposure to ozone, NO_2, SO_2, and PM has been associated with pain exacerbations, ER visits, and increased hospital admissions (Piel et al., 2017; Barbosa et al., 2015).

Furthermore, part of the increase prevalence of chronic obstructive lung disease (COPD) in adults can be traced to exposures that occurred during childhood. Exposure to high levels of PM2.5 and ozone in patients with asthma has been associated to higher risk of developing asthma–chronic obstructive pulmonary disease overlap syndrome (ACOS) (Stocks et al., 2013; Grigg, 2009). The combination of many variables such as basic lung function parameters for FEV1 and FVC, partially established at birth, genetics, prematurity, and history of bronchopulmonary dysplasia contribute to the development of COPD in the adult (Martinez, 2016).

Unfortunately, even in the intrauterine environment the developing fetus is not sheltered from air pollutants. For example, fine (PM2.5) and ultrafine (PM.1) particulate matter breathed by the pregnant mother can reach the alveolar space and from there the circulation. The resulting inflammatory response and immune system activation is not confined to the airways but disseminates and may affect the developing child. Fetal development can be adversely affected by exposure to air pollutants such as NO_2, O_3, and PM during different stages of gestation, resulting in low birth weight, small for gestational age (SGA), and preterm births, all of which are associated to increased morbidity and mortality (Mendola et al., 2016; Stieb et al., 2016; van den Hooven et al., 2012; Hyder et al., 2014; DeFranco et al., 2016; Vinikoor-Imler et al., 2014). There is data on how chronic and acute exposures to ozone, NO_2, SO_2, CO, or PM increased the risk of stillbirth (Mendola et al., 2017; DeFranco et al., 2015; Faiz et al., 2012)

Children whose mothers have been exposed to air pollution during pregnancy are at risk of neurodevelopmental disorders. Exposure to high levels of PM2.5 during the third trimester of pregnancy increased the risk of autistic spectrum disorder in children (Raz et al., 2015). Similar findings were reported by Flores-Pajot et al. who described the association between exposure to NO_2 and PM2.5 during pregnancy and increased risk of autism spectrum disorder. Although limited data, a similar trend was observed with exposure to ozone in the same study (Flores-Pajot et al., 2016). Fetal lung development can be affected by exposure to pollutants during pregnancy and persist during childhood. Six hundred and twenty children from a group of U.S. mothers exposed to high NO_2 and benzene during pregnancy had decreased lung function parameters (i.e., forced expiratory volume (FEV1), forced vital capacity (FVC), peak expiratory flow (PEF)) at the age of 4.5 years (Morales et al., 2015). To this effect, the potential adverse effects to the fetus upon exposure to air pollutants are not part of the routine counseling pregnant women receive.

The effects of air pollution on neurodevelopmental conditions in children with long-term exposures deserve special attention due to the long term implications for children in general and *all* future generations. In the early 2000s Dr. Calderón-Garcidueñas noticed that older dogs living in a highly polluted area in Mexico City, exhibited signs of dementia and disorientation. Their brains had extensive deposits of the protein amyloid b, similar to those associated to Alzheimer's disease. Similar findings were found in the brains of children with long-term exposure to air pollution in Mexico City where their cognitive deficits were associated to neuroinflammation and neurodegeneration, structural and volumetric changes and tissue changes seen in patients with Parkinson and Alzheimer's disease (Calderón-Garcidueñas et al., 2015, Calderón-Garcidueñas et al., 2016).

While the combustion of fossil fuels is a major source of air pollution, the extraction of fossil fuels is too. In many areas, fossil fuels are now primarily extracted through hydraulic fracturing (fracking), a methodology that has been linked with numerous air pollution and public health concerns. Xiuhtezcatl M.'s concern that fossil fuel exploitation in Colorado adversely impacts air and water quality, and his health, is very well founded (First Amended Complaint at ¶ 22). Data collected in Colorado, Pennsylvania, and Texas indicates that a myriad of hazardous emissions occur in conjunction with natural gas facilities. These findings are summarized in Brown et al. (2015).

Emissions Occurring in Conjunction with Natural Gas Facilities (adapted from Brown et al. (2015))
Acetaldehyde
Benzene
Butadiene
CO (carbon monoxide)
1,3, carbon disulfide
Carbon tetrachloride
Ethyl Benzene
Formaldehyde
n-Hexane
NOx (oxides of nitrogen)
PM2.5 (particulate matter less than 2.5 microns)
PM10 (particulate matter less than 10 microns)

SOx (oxides of sulfur)
Toluene
Tetrachloroethylene
2,2,4-Trimethylpentane
Trimethyl pentene
VOCs (Volatile Organic Compounds)
Xylenes (isomers and mixture)

Gas and oil extraction requires extensive diesel truck traffic with its attendant air pollution. The large volume of truck traffic also creates dust and particulate matter. For those living along haul routes, increased truck traffic increases diesel exhaust, creates noise and vibration, and creates safety risks. In addition to truck traffic, traffic also increases from an increased population of workers commuting to and from the pads. A health impact assessment (HIA) in Battlement Mesa, Colorado estimated that traffic would increase 40 to 280 truck trips per day per pad as well as 120 to a 150 additional workers commuting to the well pads.

Diesel exhaust includes various gases: carbon dioxide, oxygen, carbon monoxide, nitrogen compounds, sulfur compounds, and numerous low molecular weight hydrocarbons. Other gases include formaldehyde, acetaldehyde, acrolein, benzene, 1-3 butadiene and polycyclic aromatic hydrocarbons (PAHs). Diesel exhaust particulates include PAHs, sulfates, nitrates, metals, organics and trace elements. PAHs are carcinogenic and cause respiratory problems. Much of the particulate matter in diesel exhaust is at the PM2.5 level. PM2.5 are small enough that they bypass many of the body's protective mechanisms to enter further into the lungs than PM10. They are small enough that some may enter directly into the blood stream. Overall, PM2.5 are more hazardous than PM10. Adverse health effects associated with exposure to PM2.5 include premature mortality for infants, asthma attacks, and other respiratory symptoms (EPA, 2015). Diesel exhaust is recognized as a human carcinogen.

Hazardous air pollutants, methane, and VOC releases can occur at any stage of unconventional natural gas extraction (UGE) as is occurring in Colorado: during exploration, during production through venting, flashing, flaring, or during storage and transportation through fugitive emissions. The majority of VOC emissions during extraction come during the well completion phase, with trucks, pneumatic controllers, and drill rigs as other significant sources as well. Numerous pieces of industrial equipment are needed during UGE, including diesel trucks, diesel engines, drilling rigs, power generators, phase separators, dehydrators, storage tanks, compressors, and pipelines. Each one can be a source of methane, VOCs, nitrogen oxides, particulate matter and other gases. Methane that comes up from the well is not pure methane, but is a mixture of methane and other VOCs, and HAPs. Once methane is recovered and moved through tanks, pumps, pneumatics, and pipelines, all of those components leak to some degree, or vent by design as in the cases of pneumatic controllers, and thereby contribute to air pollution.

Flaring is the burning of methane and other gases that are not captured for commercial sale. This burning is done at the top of the stack in the open air. While new federal regulations limit flaring, there are instances in which it is still allowed. Emissions from this incomplete combustion include: VOCs, carbon monoxide, particulate matter, sulfur dioxide, nitrogen dioxide, hydrogen sulfide, acetaldehyde, acrolein, benzene, ethylbenzene, formaldehyde, hexane, naphthalene, propylene, toluene, and xylenes.

Hazardous air pollutants, methane, and other volatile organic compounds (VOCs) are leaked into the air intentionally and unintentionally. Leakage begins once flow back starts and continues from wellheads, compressor stations, storage facilities, and pipelines. There is a great deal of debate over the amount of gas leaked throughout the supply chain. One study estimated that between 3.6 and 7.9% of the lifetime production of a shale gas well is vented or leaked to the atmosphere. EPA estimates that just 1.5% of the gas produced is lost.

Although methane is the main component of the gas that is released from the ground following the hydraulic fracturing process, the gas also contains a variety of chemicals that must be separated from the methane prior to transportation in pipelines for use in businesses and homes for cooking, heating and other purposes. Benzene is one such chemical that is released from the ground along with natural gas. Although at the time of writing, there are no studies examining the relationship between benzene exposure from UGE and adverse health outcomes, there are now some studies that have looked at perinatal exposure to benzene from exposure to petroleum refineries in Texas and child health outcomes. Two studies examined populations in residential proximity to petroleum refineries and birth outcomes in the Texas birth defect registry. The studies found that women exposed to benzene during pregnancy are more likely to have children with neural tube defects and the two most common types of leukemia. McKenzie et al. (2017) found an association between maternal residence in proximity to UGE and offspring with congenital heart defects and possibly with neural tube defects. Another study in France assessed perinatal exposure to benzene by having women wear monitors to collect data on personal exposure to benzene. Women who had the most exposure to automobile and truck traffic near their homes were more likely to have children with smaller growth parameters than the women who were less exposed to traffic in their homes.

McKenzie and colleagues preformed a human health risk assessment of air emissions that quantified the risk of non-cancer and cancer endpoints. Exposure was separated into residents less than half a mile from well pads and greater than a half mile. Exposure was then determined with ambient air samples around well pads and categorized as during the well completion phase, when at least one well was undergoing uncontrolled flow-back emissions, and not during the completion phase. The results of the risk assessment found that the high exposure during the completion phase created the greatest risk due to higher exposure levels to several hydrocarbons. Residents living less than a half mile from a well had an elevated risk of both non-cancer and cancer endpoints. The elevated risk for cancer was found to be six in one million for residents greater than half a mile, and ten in one million for greater than half a mile, both of which are above EPA target of acceptable risk of one in a million. The authors found that benzene was a major component of the elevated cancer risk.

Macey et al. (2014) found markedly elevated levels of multiple air pollutants in samples taken in Arkansas, Colorado, Ohio, Pennsylvania, and Wyoming. Many of these samples were collected on residential property close to well pads (30-350 yards) at which elevated levels of benzene were measured. Macey et al. said that "[t]he results suggest that existing regulatory setback distances from wells to residences may not be adequate to reduce human health risks."

In addition to the air pollutants from the extraction of oil and gas, there are numerous other sources of air pollution associated with fossil fuels. For example, the EPA had observed that children of mothers who were exposed to increased levels of polycyclic aromatic hydrocarbons (PAHs), which are produced when gasoline is combusted, during pregnancy have a greater chance of experiencing negative effects on their neurological development, including reduced intelligence quotient (IQ) and behavioral problems, as well as respiratory effects (EPA, 2013). In the pediatric population exposure to traffic pollution, particularly benzene, has been associated to leukemia (Filippini et al., 2015).

Meanwhile, fossil fuel-powered electrical utilities and industry are the primary source of sulfur dioxide in the U.S., which is associated with respiratory symptoms for children, emergency department visits, and hospitalizations for respiratory conditions (EPA, 2013; EPA, 2015). Nitric oxide and nitrogen dioxide, which are emitted by motor vehicles as well as power plants, and engines and other equipment, are also associated with adverse health effects for children, including respiratory symptoms and respiratory-related emergency department visits and hospital admissions (EPA, 2013).

While these air pollutants are already harming children's health, because higher average temperatures and heat waves exacerbate this air pollution problem, actually increasing ground level ozone, fine particulate matter, nitrogen oxides, and sulfur oxides, the problem is only expected to get worse (EPA, 2013). These air pollutants can be harmful for children: they may contribute to the development of new cases of asthma, aggravate preexisting cases of asthma, cause decrements to lung function, increase respiratory symptoms such as coughing and wheezing, and increase hospital admissions and emergency room visits for respiratory diseases. Because children may spend a lot of time outdoors, even while exerting themselves for sports or play, they can be especially vulnerable to the impacts of poor air quality" (EPA, 2013).

In the context of the adverse effects of air pollution described above, it is our expert opinion that the Plaintiffs and other children around the U.S. are destined to a future of illness, restrictions of outdoor activities, and psychological stress. It may not be evident but air pollution is already affecting the Plaintiffs, and all children in the U.S. without discrimination by race, ethnicity, gender socioeconomic status, or education, while certain groups of children are harmed even more. In our expert opinion, the fact that today's children and all future generations have been completely immersed and will have a lifelong exposure to the detrimental effects of air pollution starting in the intrauterine environment is an alarming fact. While at this point we do not know the full magnitude or severity of the long-term outcomes of these exposures and how it will affect these children as they become adults, we do know that we have more children with asthma and aeroallergies, chronic lung disease, neurodevelopmental conditions, and repeated infections. In our expert opinion, as long as fossil fuels are being extracted and combusted, children will continue to suffer from a myriad of adverse health impacts. The only way to address those health impacts is to reduce, and eventually eliminate, our reliance on fossil fuels as our primary energy source.

IV. CLIMATE CHANGE AND EXPOSURE TO AIR POLLUTION WILL HAVE SIGNIFICANT LONG-TERM IMPACTS FOR CHILDREN REGARDING THEIR DEVELOPMENT AND SUCCESS IN LIFE

In our professional opinion, the adverse health impacts of climate change for children will result in life-long impacts. The life-long impacts will result both from repeated exposure to the impacts of climate change (until the federal government adequately responds to climate change and the threats are minimized), and also because when children experience climate-related health issues, the impacts, even from acute exposure, can result in impaired physical or cognitive development with life-long consequences.

A. Children's Exposure to Adverse Childhood Experiences Can Cause Long-term Health Impacts

There is widespread scientific literature explaining how children who are exposed to stressful or traumatic events, often referred to as adverse childhood experiences (ACEs), can experience a myriad of health problems throughout their life. Adverse childhood experiences broadly describe abuse, neglect, and other traumatic events that occur in an individual's life before the age of 18 (Felitti et al., 1998). People with excessive exposure to ACEs in childhood are more likely to die at a younger age, as well as having a host of medical and mental health problems (see **Figure 2**) (Brown et al., 2009; Foege, 1998; Chapman et al., 2004). The ACEs measured in the original Felitti study included such things as physical, sexual, and verbal abuse; physical and emotional neglect; and losing a parent to separation, divorce or other reason. Other research has shown that living in an unsafe neighborhood, being bullied, and other aspects of urban living can function as adverse childhood events (Cronholm et al., 2015). Likewise, living is a war zone has been shown, not surprisingly, to be an adverse childhood experience (Sagi-Schwartz, 2008). Another term that has been used to describe the impact of adverse childhood events on children is toxic stress. Toxic stress is living situations and experiences that activate the human body's natural stress response system in an excessive, prolonged manner (Shonkoff et al., 2009; Shonkoff et al., 2012; McEwen, 2007). Conditions that trigger chronic fear and anxiety similarly produce excessive, prolonged activation of the stress response system (National Scientific Council on the Developing Child, 2010).

In our expert opinion, many of the childhood experiences associated with climate change are ACEs, or comparable to ACEs, and cause toxic stress. Childhood displacement after major weather events is a well-documented traumatic phenomenon. The anxiety associated with living in an area experiencing repeated severe weather events, such as the Texas-Louisiana coast along the Gulf of Mexico (Weisler et al., 2006) or in areas experiencing repeated wildfires such as areas of California, Oregon, and Colorado create toxic stress (Marshall et al., 2007).

The Plaintiffs in this case who have experienced severe storms or wildfires have experienced adverse childhood events. This puts their long-term health at risk. They deserve protection from the government through actions that dramatically reduce greenhouse gas emission and thereby limit their risk of experiencing additional ACEs. Research has shown that the more ACEs children are exposed to, the greater their health risks (Felitti, 1998). These Plaintiffs, and similarly situated children throughout the U.S. have been, and continue to be, deprived of full health as a result of the government's actions that are causing climate change.

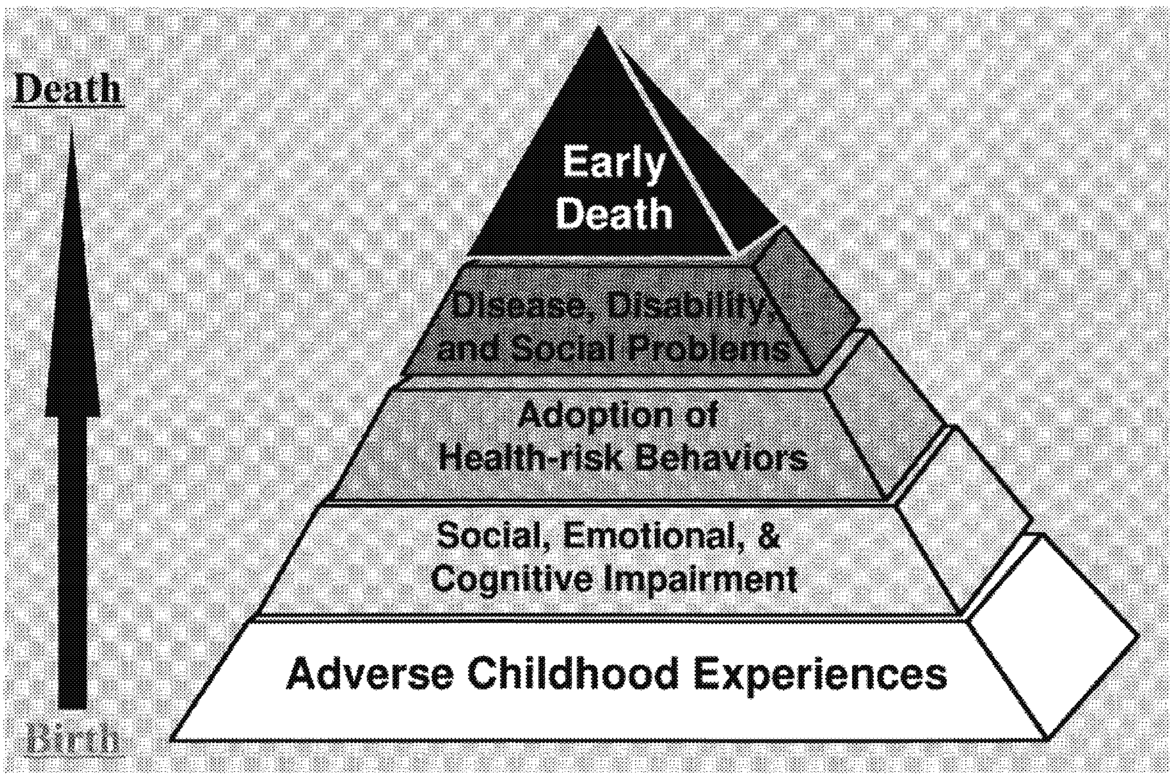

Figure 2: Illustrating the life-long impacts of adverse childhood experiences (Felitti et al., 1998).

B. Children's Exposure to Climate Change Can Cause Long-term Cognitive, Behavioral, and Mental Health Impacts, Inhibiting Children's Learning and Long-term Success

Children growing up and born today are "immersed" in climate change. Climate change is, by definition, creating an entirely new environment in which children are growing up. We will have entire generations of children who were conceived, born, and growing up in this new environment. Because this environment is unpredictable, and the threats posed by climate change are unprecedented, it makes predicting the full magnitude and severity of the impacts on children difficult. However, as described above, there is abundant evidence that the health of children is being already harmed by climate change, and in our expert opinion, the adverse health impacts will get significantly worse without immediate steps to address climate change. For example, we know, from research done in the Los Angeles area over many years, that children who grow up in an area with more air pollution have smaller lung capacity when they reach adulthood. Therefore, it is reasonable to expect that this will occur under climate change where there is a corresponding increase in air pollutants. Likewise there is information that children growing up in areas with more air pollution will have a lower IQ.

Part of children's special vulnerability comes from the fact that they have a longer "shelf-life" than do adults. Because children live longer lives, they are more likely to develop health problems that occur years after an exposure to a health threat, or after years of exposure to a threat. If, for example, it takes about 40 years for a medical problem to develop after exposure to a particular hazardous contaminant, then the 16-year-old who is exposed is more likely to live long enough to develop the cancer. Likewise, if it takes 40 years of continuous exposure to elevated levels of air pollution for a medical problem to develop, then a child with onset of exposure at 16 is more likely to manifest that problem than an adult with onset of exposure at 60. This is the situation children are facing today – they are being exposed to hazardous, carcinogenic contaminants (for example petroleum products or other fossil fuel-based toxic substances in floodwaters after an extreme weather event, which can cause health problems years later (as well as immediately); and children are exposed to continuously elevated level of air pollutants from the combustion and extraction of fossil fuels.

Children exposed to certain climate change and air pollutants, can experience changes to neurological development, with life-long consequences. For example, pregnant women are especially vulnerable to high heat, which increases the number of preterm births and incidences of low-weight babies. Birth weight is a proxy measure of fetal health and is linked to illnesses in childhood and later in life. Elevating fetal temperature by 2°C-2.5°C for just an hour can lead to moderate to severe damage to the nervous system and impede neural development (Zivin & Shrader, 2016). Excess heat in the womb can also result in both physical defects, delay brain development, and cause other central nervous system problems – all of which can lead to life-long consequences by limiting a child's educational attainment and economic prospects (Zivin & Shrader, 2016). Thus exposure to high-heat, even when just a fetus, can result in life-long consequences.

Furthermore, there are now numerous studies that link exposure to outdoor air pollution and harmful impacts on the brain. The project Targeting Environmental Neurodevelopmental Risks (TENDR) Consensus Statement stated that air pollutants-related chemicals including particulate matter PAHs, and nitrogen dioxide are "prime examples of toxic chemicals that can contribute to learning, behavioral or intellectual impairment, as well as specific neurodevelopmental disorders such as attention deficit hyperactivity disorder or autism (Bennett et al., 2016). The majority of brain development occurs before a child is born. Critical development continues until six; and further development continues into early adulthood. Neurological damage that occurs during childhood may continue to cause harm throughout the individuals' life (Perera, 2017). For example, three-year-old children exposed prenatally to high levels of PAHs had lower mental development scores on developmental tests (Perera et al., 2006). At age 5, these children performed lower on IQ tests than children with lower PAH exposure (Perera et al., 2009). As these children got older, they continued to manifest adverse neurocognitive impacts – including anxiety, depression and hyperactivity – as compared to children with lower PAH exposure (Perera et al., 2014).

Other studies have shown an association between prenatal exposure to combustion pollutants and children with autism spectrum disorders (von Ehrenstein et al., 2014; Becerra et al., 2013; Volk et al., 2014; Roberts et al., 2013; Kalkbrenner et al., 2015; Raz et al., 2015; Volk et al., 2013; Talbott et al., 2015).

There is also abundant evidence and literature on the association between climate change and mental health impacts. According to the federal government, "[t]he effects of global climate change on mental health well-being are integral parts of the overall climate-related human health impacts" (Crimins et al., 2016). Those most vulnerable to distress and other adverse mental health impacts include children. Climate change can cause purely mental health impacts but mental health impacts also tend to be associated with physical ailments. Thus, as climate change causes more physical health problems for children, the increased prevalence of the physical ailments will lead to an increase in mental health impacts.

Accordingly, Kelsey Juliana's concerns about her psychological and emotional harm, in part from projections about Oregon's water supply and other impacts of climate change, is very well founded. It is well documented that individuals suffer from anxiety and other manifestations of mental distress when confronted with the reality of climate change (Clayton et al., 2014; Clayton et al., 2017). Given the results of the studies just mentioned, Journey Z. is not alone being scared and worried about the state of the planet. Given that he lives on an island and has seen first-hand some of the changes wrought by climate change, his anxiety is based in reality and is appropriate. We would expect the mental health impacts associated with climate change to become more widespread and severe in the coming years without immediate actions by the federal government to address climate change. Whether from acute or chronic climate change impacts, mental health impacts can result in life-long challenges for children, and can even alter one's DNA and be passed on to future generations.

V. PROMPT MITIGATION STRATEGIES ARE THE ONLY SOLUTION TO PROTECT CHILDREN AGAINST CLIMATE CHANGE HARMS AND DANGERS TO THEIR PERSONAL HEALTH SECURITY

It is our expert opinion that in order to mitigate and prevent health problems associated with climate change and air pollution, decreasing atmospheric CO_2 is essential. Decreasing atmospheric CO_2 can only reasonably and rationally be achieved by ending the burning of fossil fuels and ceasing other anthropogenic sources of greenhouse gases. One can build all the sea walls that one wants to try and adapt to sea level rise. One may treat children for Lyme disease, malaria, heat exhaustion, asthma, dehydration, and other health impacts, but those measures do not deal with the overall problem and will not solve the health problems facing children and future generations. Decreasing atmospheric CO_2 concentrations and ceasing other anthropogenic sources of greenhouse gases (i.e., primary prevention), is the only way to ensure a safe and healthy future for children.

Similarly, the appropriate response to the health threats posed by lead is not just to treat children's medical conditions that result from exposure to lead, but to reduce and eliminate the use of lead and children's exposure to lead. Treating children's health problems associated with climate change, without addressing the underlying threat of climate change, would be akin to providing medical care to children exposed to lead-contaminated water in Flint, Michigan (or elsewhere), while children continue to drink water contaminated with lead – a preposterous notion. Just like it is impossible to adequately address the health threats posed by lead without eliminating children's exposure to lead, it is impossible to adequately address the health threats children face from the fossil fuel energy system and climate change without addressing the fossil fuel energy system and climate change.

CONCLUSION

The health of these Plaintiffs, along with other children, *is already harmed* by climate change and air pollution. As a result of their unique physiological features, children are especially vulnerable to the impacts of climate change, such as excess heat and extreme weather events. Children are also disproportionately vulnerable to air pollution related to the extraction and combustion of fossil fuels. At this point we know that the damage inflicted by the environmental changes imposed by the changing climate start in the intrauterine environment and continue to affect children as they grow. While children are also being impacted by climate change and air pollution, many more children, will be impacted unless the federal government addresses the climate crisis.

Sea level rise is impacting not only on the health of these Plaintiffs and other children, it is destroying the land (and islands) on which they live. It is our expert option that this loss of place will have incalculable consequences on the mental and physical health of the children so impacted. Furthermore, we are seeing changes in the patterns and severity of allergic diseases including asthma. For those Plaintiffs, and other children so impacted, this means the use of medication on a daily basis, the anxiety of not being able to breathe properly and the loss of simple childhood activities such as going outdoors to play. It is our expert opinion that the federal government's actions to promote fossil fuels have contributed to the problems sustained by these children. Severe weather events and wildfires are increasing in both severity and frequency. These events are quintessential Adverse Childhood Events. By definition, ACEs have long-term, negative impacts on the children's mental and physical health. It is our expert opinion that these problems would be less severe and less prevalent had the government implemented policies to curtail the use of fossil fuel at the time that they became aware of the threat.

Children like Plaintiff Jayden F. should not have to struggle to survive during a hurricane. Plaintiff Jaime B. should not have to worry about her family's displacement due drought and lack of water or not being able to play outdoors. Plaintiff Levi D. should not have nightmares, experience anxiety, sadness or anger about the current and future effects of climate change. They should not have to worry about moving from their home because of sea level rise. Children should be allowed to be children and should have age-appropriate concerns.

In our expert opinion, the magnitude of the threat facing these Plaintiffs, and other children, is unprecedented and will have life-long impacts for them, as well as future generations. It is also our expert opinion that this is an urgent situation. We need to start treating climate change like the public health crisis that it is. In order to address the public health threats children are facing from climate change and air pollution, the federal government must ensure that carbon dioxide emissions and other greenhouse gas emissions are severely reduced immediately. Without prompt action by the federal government to phase out fossil fuels, the government will be consigning children and future generations to lives that will undoubtedly be less enjoyable, prosperous, successful, and indeed, will be increasing cut short. The physical and psychological damage imposed by the changing climate is insidious and if we don't immediately engage in adequate mitigation strategies it will become relentless. We must protect the future of our children from climate change. The health of our children and the future of our country are not negotiable.

Signed this 13th day of April, 2018 in Houston, Texas.

Dr. Susan Pacheco, MD

Signed this 13th day of April, 2018 in Sarasota, Florida.

Jerome Paulson, MD FAAP

Dr. Jerome Paulson, MD, FAAP

Attachment 6

EXPERT REPORT
OF
HOWARD FRUMKIN, MD, MPH, DrPH

Professor of Environmental and Occupational Health Sciences
University of Washington School of Public Health

Kelsey Cascadia Rose Juliana; Xiuhtezcatl Tonatiuh M.,
through his Guardian Tamara Roske-Martinez; et al.,
Plaintiffs,

v.

The United States of America; Donald Trump,
in his official capacity as President of the United States; et al.,
Defendants.

IN THE UNITED STATES DISTRICT COURT
DISTRICT OF OREGON

(Case No.: 6:15-cv-01517-TC)

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TABLE OF ACRONYMS AND ABBREVIATIONS

ACE3:	*America's Children and the Environment*, Third Edition
CDC:	U.S. Centers for Disease Control and Prevention
CO_2:	Carbon dioxide
EPA:	U.S. Environmental Protection Agency
GHG:	Greenhouse gas
HABs:	Harmful algal blooms
IPCC:	Intergovernmental Panel on Climate Change
OPOH:	Our Planet, Our Health
PAM:	Primary amebic meningoencephalitis

INTRODUCTION

I, Howard Frumkin, am a physician and epidemiologist specializing in environmental health. I have been retained by the Plaintiffs to give my expert opinion on the health impacts of climate change, with particular emphasis on those impacts affecting children, and on present and future health impacts that will affect today's young people as they reach adulthood at a time of ongoing climate change.

QUALIFICATIONS

My professional training includes a medical degree from the University of Pennsylvania, masters and doctoral degrees in public health from Harvard University, residency training in Internal Medicine at the University of Pennsylvania and Harvard, and residency training in Environmental and Occupational Medicine at Harvard. I held faculty positions at the University of Pennsylvania School of Medicine (1988-90) and at Emory University's Rollins School of Public Health (1990-2005) and served as the Director of the National Center for Environmental Health and Agency for Toxic Substances and Disease Registry at the U.S. Centers for Disease Control and Prevention (2005-2010) and as Special Assistant to the Director for Climate Change and Health (2010) before joining the faculty at the University of Washington as Dean of Public Health, in 2010. I served as Dean through 2016 and subsequently as Professor in the Department of Environmental and Occupational Health Sciences. Commencing in May 2018, I will be heading the "Our Planet, Our Health" ("OPOH") initiative at the Wellcome Trust. OPOH is one of the world's leading research funding initiatives at the intersection of human health, climate change, urbanization, and food systems--the emerging paradigm known as planetary health. OPOH supports research on six continents, using a wide range of methods and perspectives. OPOH is committed to improving the evidence base in planetary health, to communicating that evidence effectively, and to engaging with governments, civil society, and the private sector to translate evidence into action to meet major environmental and health challenges.

Climate change and its impact on health have been one of my principal academic and scientific interests for over 20 years. I have followed the scientific literature closely during that time, and have published numerous research papers and book chapters (see **Exhibit A**). I have participated in writing and reviewing high-level reports on the health impacts of climate change, including reviewing, evaluating, and summarizing the evidence used in those reports. As a member of the Children's Health Protection Advisory Committee at the U.S. Environmental Protection Agency (EPA), I chaired the Committee's Climate Change working group. While working at the CDC, I initiated and oversaw the formation of that Agency's Climate and Health program, and served as the principal advisor to the Director on health aspects of climate change. I represented the CDC to the U.S. Global Climate Research Program. I served on the Advisory Board of the Yale Climate and Energy Institute, and on the American Association for the Advancement of Science Climate Science Panel. Beginning in May 2018, I will head the "Our Planet, Our Health" initiative at the Wellcome Trust in London, one of the world's largest sources of support for research at the intersection of health and climate change. I have spoken to numerous medical, public health, and other audiences on health aspects of climate change, and have taught this subject to undergraduate and graduate students.

This report contains my opinions, conclusions and the reasons therefore. My current curriculum vitae and a list of my relevant publications, is contained in **Exhibit A** to this expert report. My report contains citations to sources I have used or considered in forming my opinions, listed in **Exhibit B**. I am working pro bono to prepare this expert report in this action.

The opinions expressed in this expert report are my own and are based on the data and facts available to me at the time of writing. All opinions expressed herein are to a reasonable degree of scientific certainty, unless otherwise specifically stated. Should additional relevant or pertinent information become available, I reserve the right to supplement the discussion and findings in this report.

EXECUTIVE SUMMARY

Climate change, due in large part to human activity (principally the combustion of fossil fuels, and to a lesser extent land use changes and the release of climate-active air pollutants), threatens human health and well-being through a variety of pathways. The impacts on people can be divided into several categories: temperature-related effects; the effects of severe weather and disasters; the impact of reduced air quality; aggravation of allergies; increased risk of infectious diseases; nutritional effects; population displacement; civil conflict; and mental health impacts. While these risks, to some extent, will affect everybody, some groups are especially vulnerable, and children comprise one such group. The Plaintiffs in this case exemplify these vulnerabilities. Moreover, today's children will be tomorrow's adults, and will bear the risks that unfold over coming decades as the effects of climate change intensify. Climate change poses serious risks to the health and well-being of the Plaintiffs in this lawsuit.

EXPERT OPINION

Overview

Climate change affects human health through a range of pathways, as shown in **Figure 1**. Some of these are direct, such as the injuries that occur in a climate-related disaster. Some are indirect, such as nutritional challenges that result from climate impacts on crops. Still others are mediated through social processes, such as conflicts. The health effects of climate change have been extensively inventoried and reviewed, by the Intergovernmental Panel on Climate Change (IPCC),[1] by the Federal government,[2,3] in academic journals,[4-6] and in books.[7-9] Children represent a particular risk group, and the impacts of climate change on children have been specifically reviewed as well.[10-13] Below, I summarize the major health impacts of climate change, as recognized by the scientific community.

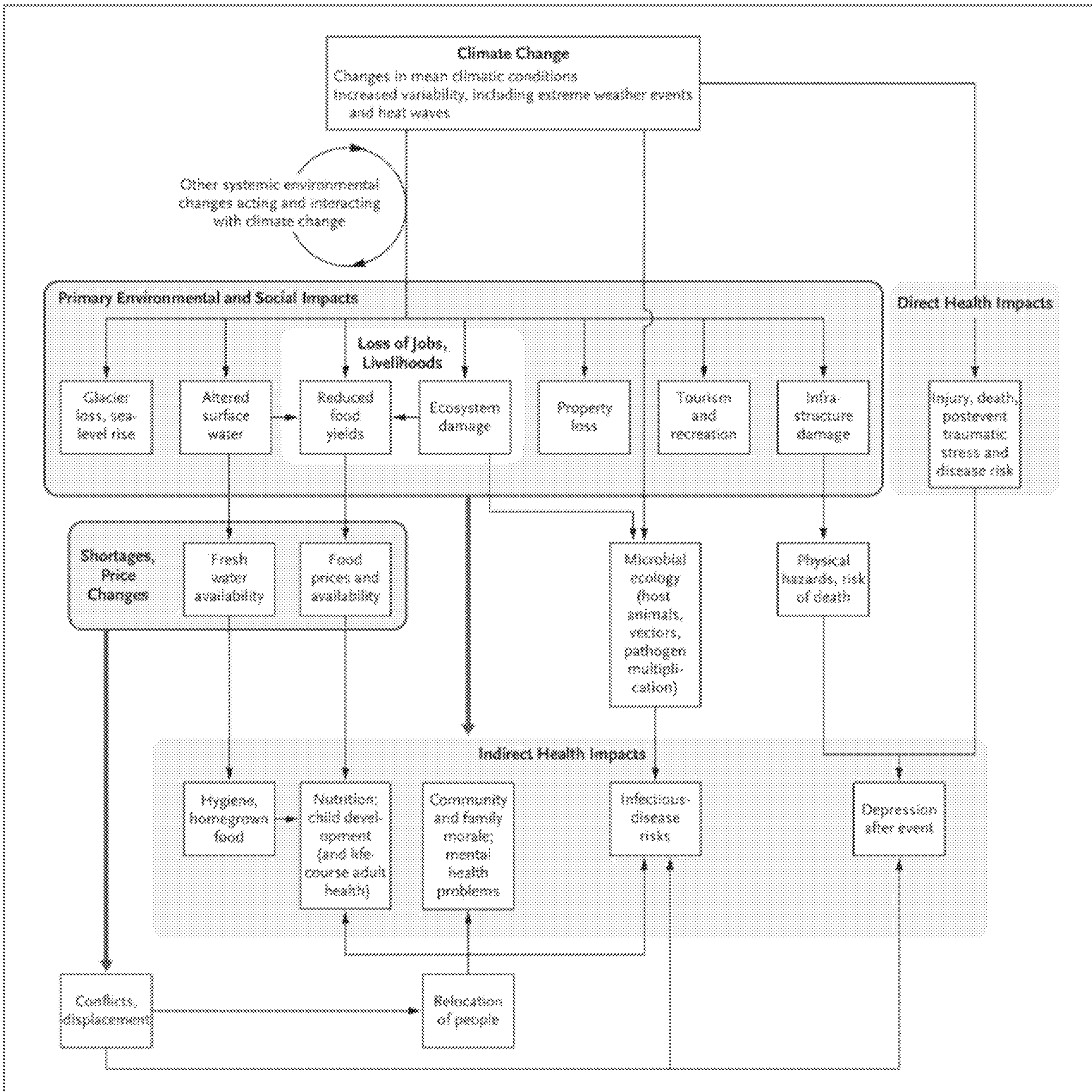

Figure 1: Processes and pathways through which climate change affects human health. Source: [4]

Temperature-related effects

Excessive heat—both during severe heat waves and as a long-term "new normal"—threatens health and well-being in numerous ways. Medical consequences range from relatively minor, self-limited conditions, such as heat rash and cramping, to severe and possibly fatal outcomes, such as heat stroke. More consequentially from a population point of view, mortality rates rise during periods of heat, mostly due to increases in cardiovascular deaths.[14] For example, the 1995 Chicago heat wave caused approximately 700 excess deaths;[15] the 2003 European heat wave had an impact two orders of magnitude higher, at an estimated 70,000 excess deaths;[16] and the 2010 Russian heat wave caused 11,000 excess deaths.[17]

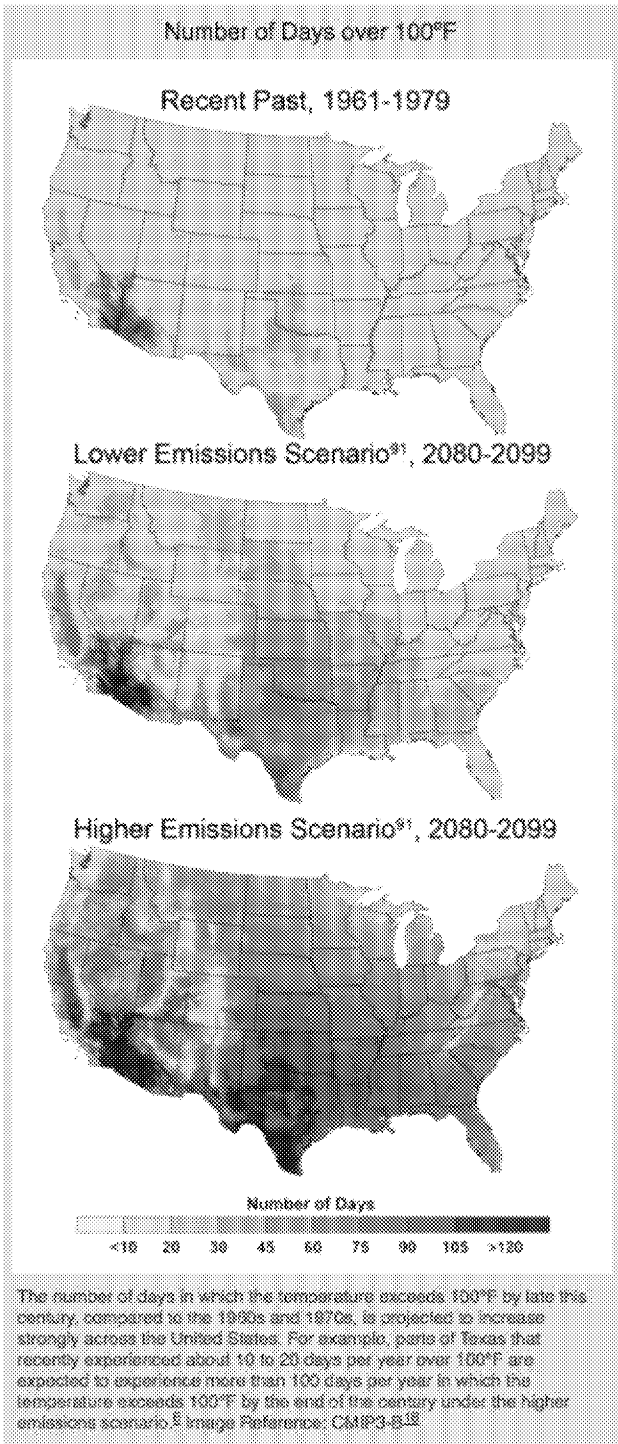

Figure 2. The number of days each year over 100°F later this century. Source: Karl TR, Melillo JM, Peterson TC, eds. *Global Climate Change Impacts in the United States.* Cambridge and New York: Cambridge University Press; 2009.

In addition to these lethal effects, heat is associated with a range of other impacts, from increased risk of kidney stones[18,19] to impaired sleep,[20] from increased violence[21,22] to substantial reductions in work capacity (with serious social and economic consequences).[23,24] Concomitant trends affect the risk posed by heat. For example, urbanization concentrates people in metropolitan areas, where the urban heat island effect amplifies the impact of rising temperatures.[25,26] Similarly, heat not only creates its own risks, but also reduces air quality by driving ozone formation; ozone is a respiratory toxin.[27] Some acclimatization to heat is possible, both physiologically and socially (through such means as air conditioning), but there are limits to adaptability. In coming years, extremely hot days will become more common (**Figure 2**).[28] Warmer weather will reduce the number of cold-related deaths in some areas, but not enough to compensate for projected increases in heat-related deaths.[29] Deprived populations such as the poor, those who are socially isolated, people of color, the very old, people with certain medical conditions, and outdoor workers are at especially high risk from severe heat.[3,30,31] Importantly, so are young people.[32] The risk begins as early as the prenatal period (heat increases the risk of preterm birth[33-35]) and continuing into infancy (a high-risk age group for mortality during heat waves[32]), later childhood (children's visits to physicians and emergency rooms increase disproportionately during heat waves[32,36]), and the teen years (when hot days endanger high school athletes[37]).

Severe weather and disasters

Severe weather events have been rising in frequency in recent decades, and continued increases are predicted.[38,39] For example, a recent analysis considered sea level together with wave, tide, and storm surge models; the authors reported that extreme flooding will become substantially more frequent along the Pacific coast, from California to Washington state, by 2050.[40] Such events are dangerous. Floods, hurricanes, and severe storms can cause traumatic injuries and death at the time of their occurrence. Other health impacts can persist well beyond the acute phase. In the short term, for example, before power is restored, people who utilize propane burners and generators face a risk of carbon monoxide poisoning.[41] Disasters often disrupt medical care, and can destroy clinical facilities, interfering with acute and chronic medical care.[42,43] Following floods, homes can experience extensive mold growth, posing respiratory risks.[44] In contrast to severe storms, droughts unfold more slowly, over months to years, threatening health in a range of ways: infectious disease risks due to reduced water quality and quantity, respiratory risks due to reduced air quality, and mental health risks.[45] In the aftermath of disasters, people's lives may be upended and their livelihoods compromised, and they may be forced to relocate; these outcomes threaten mental health, manifested in elevated rates of anxiety, depression, post-traumatic stress disorder, substance abuse, and domestic violence following disasters.[46] Deprived populations, such as poor and minority communities, and communities located in vulnerable places, are at increased risk from disasters caused or intensified by climate change.[47,48] Again, children face disproportionate risk from extreme events.[49] As noted by the American Academy of Pediatrics, "Extreme weather events place children at risk for injury, loss of or separation from caregivers, exposure to infectious diseases, and a uniquely high risk of mental health consequences, including posttraumatic stress disorder, depression, and adjustment disorder. Disasters can cause irrevocable harm to children through devastation of their homes, schools, and neighborhoods, all of which contribute to their physiologic and cognitive development."[10]

Air quality

Climate and other environmental changes affect the air that people breathe in diverse ways. First, the combustion of fossil fuels—a root cause of climate change—is also a leading source of many air pollutants (https://www.epa.gov/air-emissions-inventories). Air pollutants, including particulate matter, ozone, oxides of sulfur and nitrogen, and others, increase the risk of cardiovascular disease, respiratory disease, cancer, and other illnesses.[50] These impacts are so extensive that they generate billions of dollars in health care costs each year nationally.[51-53]

Climate change affects air quality in at least two other important ways.[54,55] First, warmer temperatures drive the formation of ozone, a respiratory toxin.[54,56] Higher ozone levels are reflected in increases in respiratory symptoms, lost work and school days, hospital and emergency department visits, and premature deaths.

Second, drier, hotter weather and degraded forests (due to such factors as pest infestations) have resulted in more frequent wildfires.[57] Wildfires release large amounts of smoke, a cardiopulmonary risk for those downwind.[58,59] For example, during September 2017 wildfires in the region caused those Plaintiffs from Washington and Oregon to be exposed to hazardous levels of smoke for several days in a row (**Figure 3**).

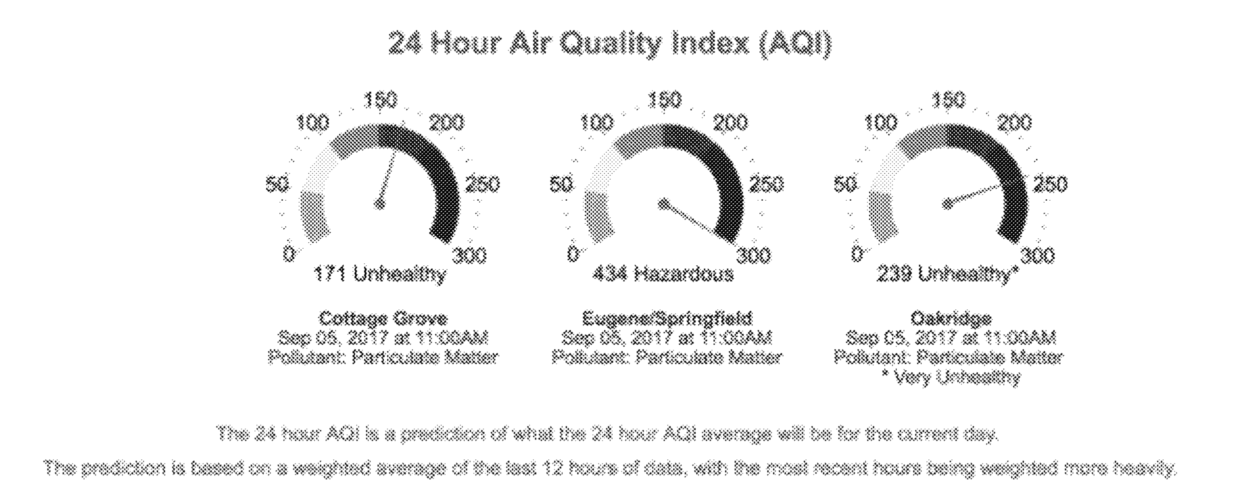

Figure 3: Air quality suffers due to wildfire smoke in Lane County, Oregon. The Air Quality Index for September 5, 2017, as reported by Lane Regional Air Protection Agency.

People with respiratory conditions such as asthma are especially susceptible to the effects of air pollutants.[60] So are children, owing to their narrow airways, their relatively high respiratory rates, and other factors;[61] as a result, worsening climate change, and resulting air quality degradation, are projected to pose a particular risk for children.[62]

Allergies

Climate change can exacerbate allergies in several ways. First, some allergenic plants such as ragweed and some allergenic trees experience faster growth and a prolonged growing season—a trend that has been documented in many parts of the United States.[63,64] Second, these plants can produce more pollen (**Figure 4**). Third, the amount of allergenic proteins contained in pollen can increase.[65,66] The result is increased suffering for people with allergies.[67]

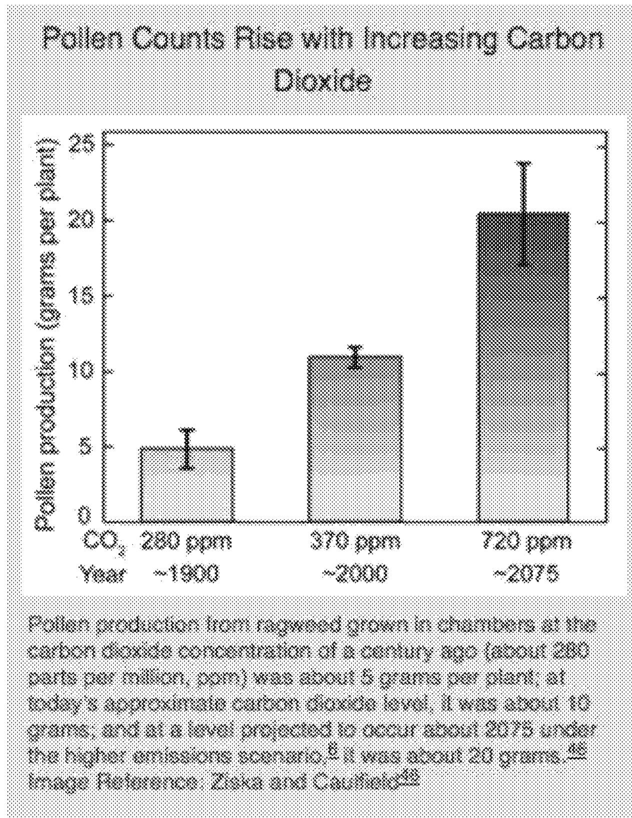

Figure 4. Rising ragweed pollen counts with rising CO_2 levels. Karl TR, Melillo JM, Peterson TC, eds. *Global Climate Change Impacts in the United States*. Cambridge and New York: Cambridge University Press; 2009.

Climate change also is also likely to exacerbate allergy symptoms, as well as asthma, through indirect pathways. For example, climate change worsens air quality—a problem for people with allergies since air pollution potentiates allergic symptoms.[68] Similarly, climate change is associated with more frequent thunderstorms, which are in turn associated with exacerbations of asthma and allergic symptoms.[69-72] As asthma and allergies have become more widespread in recent years, the at-risk population for these impacts has also grown.[73-75] Allergies are highly prevalent among children,[76] and can affect their physical and emotional health by interfering with sleep, play, and school attendance and performance.[77-79]

Harmful algal blooms

Harmful algal blooms (HABs) occur when colonies of algae along seacoasts or in fresh water bodies proliferate, and produce toxic effects on people, pets, aquatic species, and birds. The causes of harmful algal blooms are complex, but growing evidence suggests that climate change contributes to these events.[80-82] Human illnesses from HABs, while not common, can feature severe symptoms ranging from diarrhea to respiratory illness to neurotoxicity, and may even be fatal.[83,84] HABs can harm people in other ways, by limiting recreational opportunities and the ability to eat fish and shellfish. Children are at particular risk from HABs due to their smaller body size, risky behaviors, and developmental stage.[85]

Infectious diseases

Climate change is likely to increase the risk of infectious diseases.[86] Two main categories of disease are especially salient: vector-borne diseases, and water- and foodborne diseases.

Vector-borne diseases are those that are spread by mosquitoes, ticks, and similar organisms.[87] Mosquitoes transmit such diseases as dengue fever,[88] malaria,[89] and West Nile virus;[90] and ticks such diseases as Lyme disease.[91-93] Many features of climate change can promote disease spread: changes in rain patterns that enhance mosquito habitat; changes in temperature that accelerate vector metabolism, breeding, and feeding; changes in vegetation that favor tick proliferation.[94] Some vector-borne diseases, such as Lyme disease, have expanded their geographic range and/or seasonal distribution in recent years (**Figure 5**; www.cdc.gov/lyme/stats/index.html). This trend is expected to continue in coming decades due to ongoing and worsening climate change (**Figure 6**).[91,95]

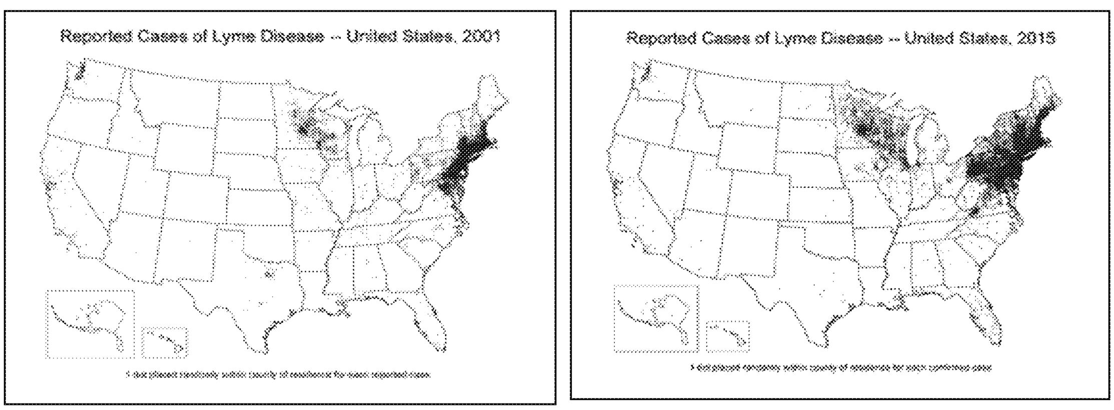

Figure 5: Increase in reported cases of Lyme disease in the US, in 2001 (on left) and 2015 (on right). Source: Centers for Disease Control and Prevention.

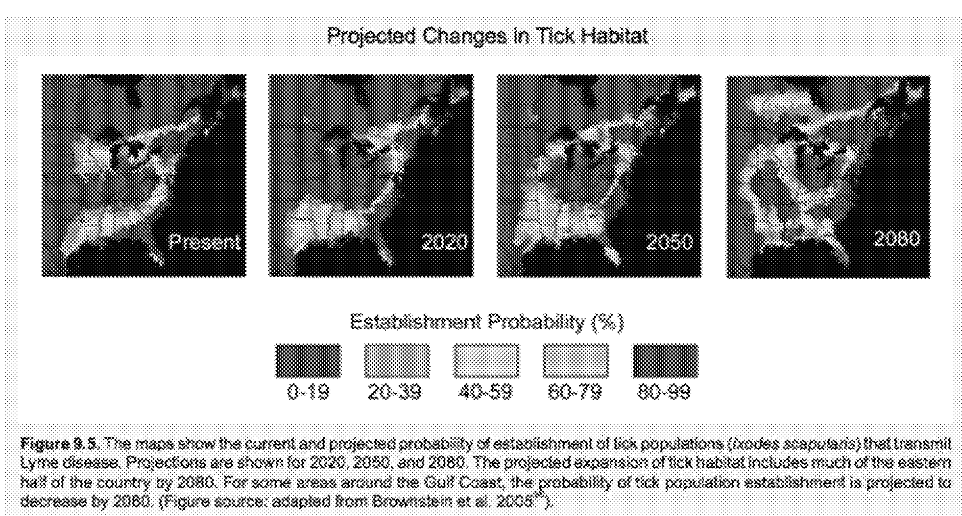

Figure 6: Projected expansion of conditions favorable to ticks that transmit Lyme disease. Source: Melillo JM, Richmond TC, Yohe GW, eds. *Climate Change Impacts in the United States*. U.S. National Climate Assessment. U.S. Global Change Research Program, 2014. https://www.globalchange.gov/browse/multimedia/projected-changes-tick-habitat.

Other vector-borne diseases, such as dengue fever, which were previously rare in the U.S. except in returning travelers, have begun to appear as locally acquired cases in several states during the last decade,[96,97] and the risk of these diseases is expected to grow with advancing climate change.[98] Vector-borne disease spread is complex, and depends on many factors other than climate change, such as land use changes and the use of protective strategies (e.g., window screens, insect repellant). But continued climate change is likely to bring continued increased risk.

Also important are infectious diseases transmitted by water and food, such as cholera,[99] salmonella, and campylobacter.[100] The risk of these conditions may increase due to changes in hydrology, pathogen biology, and other factors. Two cardinal features of climate change are associated with increases in waterborne diarrheal diseases: warm weather[101,102] and severe rainfall events.[103,104] This suggests that continued climate change will increase the risk of waterborne infections. Foodborne diseases and waterborne diseases are closely linked, since food is often contaminated by water, and since the conditions that promote one also promote the other. Accordingly, climate change is expected to increase the risk of foodborne diseases as well.[105]

Evidence links other infectious diseases with climate and/or weather. One example is fungal diseases, because temperature, moisture, and wind conditions affect the growth and dispersal of fungi. Coccidioidomycosis, or "Valley Fever," is a fungal infection found mainly in Arizona and California. The incidence of this disease has risen considerably in recent decades,[106] and it has appeared in previously disease-free locations such as eastern Washington state.[107] There is evidence that changing rainfall patterns have contributed to this increase.[108,109] Another example is *Naegleria fowleri*, an amoeba that causes a devastating brain infection, primary amebic meningoencephalitis (PAM). This disease is acquired by swimming in contaminated water. Because lakes cannot support the *Naegleria* amoeba below a certain temperature, this has been a disease of the southern U.S. However, it recently emerged in Minnesota, where it killed a child. Investigation revealed that lake water where the child had swum and contracted the infection had reached record high temperatures.[110] Such risks—some known, some not yet recognized—will be a feature of continued climate change.

For many infectious diseases, those at greatest risk include the very young, the very old, and people with certain underlying illnesses or who are immunocompromised. Children have immature immune systems, and less resilience than adults to some abnormalities such as dehydration (a result of severe diarrhea).

Nutrition

Climate change threatens agricultural productivity in many parts of the world through complex pathways, including the effects of extreme heat, storms, droughts, and flooding; pests and weeds; and rising ozone levels.[111-113] Compounding these impacts on crops themselves is reduced work capacity among farmers.[24] The quantity of crops produced is not the only concern; quality also suffers. The protein and nutrient content of some grains and legumes, including wheat, rice, corn, and soy, declines with rising atmospheric concentrations of carbon dioxide (CO_2).[114] Fish represent a substantial source of dietary protein for many populations, but global fisheries, already compromised by overfishing,[115] are threatened by climate change, especially at low to mid-latitudes,[116,117] and aquaculture—potentially an important adaptation—is particularly threatened by ocean acidification.[118] Livestock production, including animal growth and milk production, is depressed with hot weather and other features of climate change.[119] Some regions, such as northern Canada and Russia, will enjoy improved agricultural output, but many more will suffer declines. When food supplies fall short of demand, prices rise, a special hardship for people who are food-insecure—including about one in eight U.S. households.[120] Families that have difficulty making ends meet tend to purchase less costly, less nutritious, calorie-dense foods[121,122]—a contributor to a range of chronic diseases.

Population displacement

In the U.S., as in much of the world, human habitation is concentrated in areas that are vulnerable to climate change—along coasts and rivers, and in warm climates. Some populations may be displaced with climate change, as drought, sea level rise, and severe weather events create shortages of food, water, and habitable land in vulnerable places.[123,124] This may occur relatively acutely, such as after a major disaster, or more deliberately and over a longer time frame, as places become progressively less habitable (or as it becomes prohibitively expensive to keep them habitable).[125,126] Key health risks among displaced populations relate to infectious diseases, nutrition, reproductive health, and mental health and psychosocial stressors.[127,128] Children are especially vulnerable to these impacts, especially those related to psychosocial stressors.[129,130]

Civil conflict

Worsening pressure on increasingly scarce resources, displaced populations, and other destabilizing forces are risk factors for civil conflict.[131-133] Changing weather patterns due to climate change may have contributed to the Darfur conflict in the first decade of the present century,[134] and to the uprisings in Syria and Egypt in the following decade.[135] Accordingly, the U.S. Department of Defense has identified climate change as a serous security threat.[136] The implications for health are both direct, threatening the safety of U.S. service members required to engage in armed conflicts, and indirect, diverting funds from health and other human services. At a more granular scale, warming temperatures are associated with higher levels of interpersonal violence,[21,137] resulting in injuries and fatalities, lasting psychological damage, and other harms.[138] Children are vulnerable to lasting effects from exposure to violence during childhood; such exposure is associated with medical, mental health, social, and behavioral problems both during childhood and during the adult years.[139-141]

Mental health impacts

Climate change and environmental degradation can threaten mental health in several ways. Disasters such as floods and hurricanes, as noted above, often result in large population burdens of depression, anxiety, and other manifestations of post-traumatic stress,[142] with children especially vulnerable.[129,130] The ongoing interruption of place attachment; the loss of accustomed weather patterns, biodiversity and other environmental features; and the insecurity that comes with uncertainty about the future, can trigger grief, distress, anxiety, and other mental disorders.[143-145] People with mental illnesses are also more susceptible to heat, because of the side effects of certain medications, inappropriate behavioral responses, and/or abnormal physiological homeostatic mechanisms.[146]

Children have specific vulnerabilities

In the context of this litigation, the risks of climate change for children are especially relevant. As noted above, children are particularly vulnerable to many of the health risks posed by climate change.[10,12,147] These include the effects of heat,[32] drought,[148] disasters[149-151] and resulting displacement,[129] air pollution,[152] allergen exposure,[67] and many infectious diseases, from dengue fever[153] to diarrhea.[154] As one recent commentary by a leading researcher noted, children "bear a disproportionate burden of disease and developmental impairment from both environmental pollution and climate change due to the combustion of coal, oil, gasoline, diesel and natural gas."[155] Climate change poses a wide range of risks that directly target children.

The Plaintiffs in this case exemplify the risks discussed here

The Plaintiffs in this case exemplify the health risks discussed above. First, according to the First Amended Complaint and Plaintiff declarations I reviewed, several of the Plaintiffs have medical conditions that place them at risk of one or more of the impacts described above, in particular asthma (Isaac V., Sahara V., Alex Loznak, and Nathan B.) and allergies (Levi D., Victoria B., Kiran Oommen, Jaime B., Zealand B., Sahara V., Avery M., Sophie K., Alex Loznak, and Nathan B.). Second, several of the Plaintiffs live in places where impacts such as wildfires, water scarcity, and coastal ecosystem changes have traumatized them and/or constrained their outdoor recreation opportunities (Xiuhtezcatl M. in Colorado; Kelsey Juliana, Tia Hatton, Kiran Oommen, Zealand B., Sahara V., Hazel V., Avery M., Miko V., Jacob Lebel, and Alex Loznak in various parts of Oregon; Levi D. on the Florida coast; Journey Z. on the Hawaiian coast; Jaime B. in Arizona; Aji P. in Washington; Sophie K. in Pennsylvania; Nicholas V. in Colorado; and Nathan B. in Alaska). Outdoor recreation is an important means of promoting children's health and development,[156-158] and interrupting access to such opportunities compromises health. Few places are immune from the health threats posed by climate change; for example, many of the Plaintiffs reside in Oregon, where climate-related risks to health have been well documented by the Oregon Health Authority.[159] Third, many of the Plaintiffs report sadness, anxiety, and fear regarding the future, reflecting their awareness of the risks of climate change; these reactions undermine mental health and happiness.[160,161] This inventory of specific risks in these individual children is by no means exhaustive; most of the risks discussed in this testimony will operate, to a greater or lesser extent, on most of the Plaintiffs in this case, as climate-related risks will affect all children. However, the broad nature of the health impacts of climate change in no way diminishes the specific risks to these Plaintiffs.

Government awareness of risks posed to youth by climate change

In August 2005, the U.S. EPA's Children's Health Protection Advisory Committee sent a formal letter to then-EPA Administrator Steven Johnson, entitled "Children's Environmental Health and Climate Change" (available at https://www.epa.gov/sites/production/files/2014-

05/documents/8302005.pdf). As Chair of the subcommittee on climate change, I led the preparation of that letter. The letter stated that

> *"Climate change will affect children's environmental health, in some cases disproportionately,"* noting that *"Children are especially vulnerable because of their developing organ systems, their high risks of certain exposures, and other reasons."*

and recommended that

> *"EPA should use all available regulatory authority to reduce greenhouse gases [GHGs] to avoid an irreversible course of global climate change with attendant harm to children."*

Administrator Johnson responded in November 2005 (available at https://www.epa.gov/sites/production/files/2014-05/documents/11182005.pdf) noting that: "The Agency and the Bush Administration agree that climate change is a priority."

In January 2013, the U.S. EPA published *America's Children and the Environment, Third Edition*, EPA 240-R-13-001. Among the important points made by this publication are the following:

> *"America's Children and the Environment, Third Edition ("ACE3") is EPA's report presenting data on children's environmental health. ACE brings together information from a variety of sources ...." (p. 6).*
>
> *"Climate change may increase children's exposure to extreme temperatures, polluted air and water, extreme weather events, wildfires, infectious disease, allergens, pesticides, and other chemicals. These exposures may affect children's health in a number of direct and indirect ways. It is important to note that climate change will likely result in a mix of both positive and negative health impacts. For example, warmer summers may increase the number of heat-related injuries and deaths, while warmer winters may result in fewer cases of cold-related injuries and deaths. (Footnote omitted.) The effects of climate change will also vary from one location to another and will likely change over time as climate change continues. (Footnotes omitted.) Furthermore, the human health risks from climate change may be affected strongly by changes in health care advances and accessibility, public health infrastructure, and technology. (Footnotes omitted)." (p. 105).*
>
> *"Climate change is likely to change the timing, frequency, and intensity of extreme weather events, including heat waves, hurricanes, heavy rainfall, droughts, high coastal waters, and storm surges. (Footnotes omitted.) These events can cause traumatic injury and death, as well as emotional trauma. Extreme weather events are also associated with increased risk of food- and water-borne illnesses as sanitation, hygiene, and safe food and water supplies are often compromised after these types of events. (Footnotes omitted.) One study found that periods of heavy rainfall were associated with increased emergency*

room visits for gastrointestinal illness among children. (Footnote omitted.) Heavy rainfall may result in flooding, which can lead to contamination of water with dangerous chemicals, heavy metals, or other hazardous substances from storage containers or from preexisting chemical contamination already in the environment. (Footnotes omitted.) Elevated temperatures and low precipitation are also projected to increase the size and severity of wildfires. This can lead to increased eye and respiratory illnesses and injuries, which include burns and smoke inhalation. (Footnote omitted.) Extreme weather events can be especially dangerous for children because they are dependent on adults for care and protection. (Footnote omitted.)" (p. 106).

"Through various indirect pathways, climate change may lead to increasing levels and/or frequencies of childhood exposure to harmful contaminants. (Footnotes omitted.) Changes in temperature, rainfall, and crop practices related to climate change are likely to affect exposure to pathogens, pesticides, and other chemicals in a number of ways. Broader geographic distribution of pests and increased growth of invasive weeds will likely lead to greater use of pesticides. (Footnotes omitted.) Increased precipitation and increased variability in precipitation are likely to increase pathogen and contaminant levels in lakes and other surface waters. (Footnotes omitted.) The distribution of chemicals in the environment is likely to change: for example, an increase in ice melts caused by a warming climate may release some past emissions of globally transported chemicals, such as polychlorinated biphenyls (PCBs) and mercury, that have been trapped in polar ice. (Footnotes omitted.) Increasing concentrations of these chemicals in the atmosphere, and subsequent deposition to land and water, have the potential to increase concentrations of these chemicals in fish and other foods derived from animals. Warmer water temperatures may also increase the release of chemical contaminants from sediments, increasing their uptake in fish. (Footnote omitted.) Climate change may result in children spending more time indoors. Buildings that are tightly sealed in response to adverse weather conditions may result in increased exposure to contaminants from poor ventilation and higher concentrations of indoor pollutants such as radon, environmental tobacco smoke, and formaldehyde. (Footnote omitted.)" (p. 107).

"Children are expected to be especially sensitive to the effects of climate change for a number of reasons. Young children and infants are particularly vulnerable to heat-related illness and death. (Footnote omitted.) Compared with adults, children have higher breathing rates, spend more time outside, and have less developed respiratory tracts—all making children more sensitive to air pollutants. Additionally, children have immature immune systems, meaning that they can experience more serious impacts from infectious diseases. (Footnote omitted.) The greatest impacts are likely to fall on children in poor families, who lack the resources, such as adequate shelter and access to air conditioning, to cope with climate change. (Footnote omitted.)" (p. 107).

Finally, ACE3 cites Chapter 9, the health chapter, of the Third National Climate Assessment.[162] ACE3 does not directly quote from this chapter, but cites the chapter at numerous points, including the following:

> *"Climate change is projected to harm human health in a variety of ways through increases in extreme temperature, increases in extreme weather events, decreases in air quality, and other facts." (p. 25).*
>
> *"There are a variety of other impacts driven by climate change that are expected to pose significant health hazards, including increases in wildfire activity." (p. 25).*
>
> *"Extreme temperatures are projected to rise in many areas across the U.S., bringing more frequent and intense heat waves and increasing the number of heat-related illnesses and deaths." (p. 28).*
>
> *"These physical impacts on water quality will also have potentially substantial economic impacts, since water quality is valued for drinking water and recreational and commercial activities such as boating, swimming, and fishing." (p. 32).*

I have similarly communicated the health risks associated with climate change to Federal governmental bodies in the past. For example, on April 9, 2008, I testified on "Climate Change and Public Health" before the Select Committee on Energy Independence and Global Warming of the United States House of Representatives. At the time, I was Director of the CDC's National Center for Environmental Health and of the U.S. Agency for Toxic Substances and Disease Registry. A true and correct copy of my testimony is attached here as **Exhibit C**. Among the additional points I made during my testimony were the following:

> At p. 3, I noted that, while knowledge of the potential public health impacts of climate change will advance in the coming years and decades, the following are current best estimates of major anticipated health outcomes:
>
> • Direct effects of heat,
> • Health effects related to extreme weather events,
> • Air pollution-related health effects,
> • Water- and food-borne infectious diseases,
> • Vector-borne and zoonotic diseases, and
> • Other pathogens sensitive to weather conditions.
>
> At p. 5, I stated that "climate changes will likely affect air quality by modifying local weather patterns and pollutant concentrations, affecting natural sources of air pollution, and promoting the formation of secondary pollutants. Studies show that higher surface temperatures, especially in urban areas, encourage the formation of ground-level ozone. Ozone can irritate the respiratory system, reduce lung function, aggravate asthma, and inflame and damage cells that line the lungs.

> In addition, it may cause permanent lung damage and aggravate chronic lung diseases."
>
> At p. 7, I observed some demographic groups are more vulnerable to the health effects of climate change than others. Children are at greater risk of worsening asthma, allergies, and certain infectious diseases.

Therefore, the public health risks I describe in this report have been well known by the Federal government for a substantial period of time.

Today's children will be tomorrow's adults

Today's children will not be children forever; they are tomorrow's adults. After that, they will reach old age. The risks of climate change will therefore play out over the course of their lives, threatening today's children with cumulative risks that intensify over coming decades. Some exposures, sustained during childhood, raise the risk of adult diseases. Other risks will continue to operate on them as adults. And given the current trajectory of climate change—steadily rising temperatures, more chaotic weather, and related changes during coming decades—today's children can anticipate a lifetime of worsening risks. Each of the health effects described above poses risks not only to children, but also to adults. And each of these risks is increasing.

CONCLUSION

Based on the foregoing discussion, it is my expert opinion that climate change disproportionately threatens the physical and mental health, and well-being, of children as a class of people. Today's children already bear, and will continue to bear, a substantial climate health burden, both in their youth, and cumulatively as they reach adulthood and mature into old age. At least some of the Plaintiffs in this case, based upon their declarations and their allegations in the First Amended Complaint and my expert opinion, are already suffering health problems of the type that climate change aggravates and/or makes more likely, and such health impacts will worsen as temperatures continue to rise. Government actions that further exacerbate the severity of climate change, as well as the failure to take action to reverse climate change, represent substantial and serious threats to the health of these children.

It is my expert opinion that, while adaptation can offer some protection, it cannot fully counter the health risks of climate change, and that prevention is essential. Prevention, in this context, means prompt and aggressive action to eliminate the human causes of climate change. This will not prevent all of the public health impacts of climate change, since some are inevitable given the "climate commitment" already in place,[163] but it will reduce the risk and limit the cumulative harms experienced over the lifetimes of these children.

Signed this 10th day of April, 2018 in Seattle, Washington.

Howard Frumkin, MD, MPH, DrPH

Attachment 7

EXPERT REPORT
OF
FRANK ACKERMAN

Principal Economist, Synapse Energy Economics

Kelsey Cascadia Rose Juliana; Xiuhtezcatl Tonatiuh M.,
through his Guardian Tamara Roske-Martinez; et al.,
Plaintiffs,

v.

The United States of America; Donald Trump,
in his official capacity as President of the United States; et al.,
Federal Defendants.

IN THE UNITED STATES DISTRICT COURT
DISTRICT OF OREGON

(Case No.: 6:15-cv-01517-TC)

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TABLE OF ACRONYMS AND ABBREVIATIONS

CO_2:	carbon dioxide
CBA:	cost-benefit analysis
DICE:	Dynamic Integrated Climate-Economy
FUND:	Climate Framework for Uncertainty, Negotiation and Distribution
IAM:	integrated assessment model
IWG:	U.S. Federal Government Interagency Working Group
kwh:	kilowatt hour
MWh:	megawatt hour
NAS:	National Academy of Sciences
OMB:	Office of Management and Budget
PAGE:	Policy Analysis of the Greenhouse Effect
PPA:	purchased power agreements
SCC:	social cost of carbon
VSL:	value of a statistical life
WTA:	willingness to accept
WTP:	willingness to pay

INTRODUCTION

I, Frank Ackerman, have been retained by Plaintiffs in the above-captioned matter to provide expert testimony regarding the economic consequences of human-caused climate change and the economic feasibility of a swift transition off of fossil fuels for energy. In this report, I examine multiple reasons why conventional economic analyses, such as those relied on by the Defendants, knowingly undervalue or dismiss the serious risks of climate damages that Defendants are in the process of imposing on the Youth Plaintiffs here and on future generations. These reasons include the standard approaches to discounting, the treatment of extreme risks and irreversible losses, reliance on flawed techniques of cost-benefit analysis, use of limited and often biased damage estimates, and specific choices made in calculating the "social cost of carbon" (SCC, i.e. the cumulative value of damages caused by a ton of CO_2 emissions). I also briefly discuss the surprisingly low, and declining, costs of emission reduction, which make active, large-scale climate protection policies more feasible.

As evidenced by my CV, I have written extensively about the economics of climate change, energy, and other environmental problems. I have particular expertise on the limitations of traditional cost-benefit analyses. I have written several books that address these issues, including *Worst-Case Economics: Extreme Events in Climate and Finance* (2017); *Climate Economics: The State of the Art* (2013); *Can We Afford the Future? The Economics of a Warming World* (2008); and *Priceless: On Knowing the Price of Everything and the Value of Nothing* (2004). I received my PhD in economics from Harvard University and have taught economics at the Massachusetts Institute of Technology, Tufts University, and the University of Massachusetts. I am a founder and member of the Steering Committee of Economics for Equity and Environment and a member scholar of the Center for Progressive Reform.

I also have significant professional experience in the private and nonprofit sectors, including work as: Principal Economist for Synapse Energy Economics, Inc. (2012 - present); Senior Economist and Director of Climate Economics Group for the Stockholm Environment Institute's U.S. Center (2007 - 2012); and Senior Economist for the Tellus Institute (1985 - 1995). My clients have included the European Parliament, the U.S. Environmental Protection Agency, and the Environment, Economics and Society Institute. I have testified on the economic implications of global climate change to the United States Congress House Committees on Energy and Commerce and Ways and Means, and I have testified on energy and environmental concerns at a variety of state agency hearings.

This expert report contains my opinions, conclusions, and the reasons therefore. My CV, which includes a list of publications I have authored in the last ten years, is contained in **Exhibit A** to this expert report. In preparing my expert report and testifying at trial, I am deferring my expert witness fees to be charged Plaintiffs given the financial circumstances of these young Plaintiffs. If a party seeks discovery under Federal Rule 26(b), I will charge my reasonable fee of $280 per hour for the time spent in addressing that party's discovery. I have not provided previous testimony within the preceding four years as an expert at trial or by deposition. I have, however, provided expert witness testimony in several utility regulatory proceedings. My report contains citations to all documents that I have used or considered in forming my opinions, listed in **Exhibit B** to this expert report.

The opinions expressed in this expert report are my own and are based on the data and facts available to me at the time of writing, as well as based upon my own professional experience and expertise. All opinions expressed herein are to a reasonable degree of scientific certainty, unless otherwise specifically stated. Should additional relevant or pertinent information become available, I reserve the right to supplement the discussion and findings in this expert report in this action.

EXECUTIVE SUMMARY

There are multiple grounds for believing that the economic analyses relied on by Defendants to inform climate and energy policy in the United States, knowingly underrepresent costs of climate disruption, thus undervalue the damage that Defendants are imposing on Youth Plaintiffs and future generations, and exaggerate the cost of reducing that damage today. One result of these biases is that the Obama Administration's estimate of the social cost of carbon ("SCC"), a measure of the severity of climate damages and the urgency of policy responses, was much too low, an affirmative step that placed these Youth Plaintiffs at significant risk. Defendants' underrepresentation and undervaluation of climate damages affirmatively placed these Youth Plaintiffs in a worse position than that in which they would have been had Defendants based their actions on recognition of the true costs, thereby predictably exposing these Youth Plaintiffs to the actual, particularized, and obvious dangers of climate disruption.

The treatment of discounting by Defendants frames their economic analysis of long-term problems such as climate change and has resulted in a policy or practice by Defendants that deliberately devalues the climate harms that Defendants know these Youth Plaintiffs will experience over the long term. Discount rates have immense influence on the results of economic analyses, particularly in an intergenerational context. How much less are future costs and benefits worth today, solely because they will occur in the future? If a high discount rate is used, the costs and benefits that will be experienced 100 years from now are worth almost nothing today, suggesting that climate mitigation (or other policies that benefit future generations) are not worth spending much on today. At a low discount rate, such as the 1.4% annual rate adopted by the Stern Review (Stern 2007), the present value of future impacts is much more substantial, endorsing policy-making as if the future mattered. Within the economic debates over discount rates, there are many strong rationales for very low, and even zero, discount rates. This is important because a very low discount rate is required in order to recognize the importance of climate impacts on future generations and their wellbeing in Defendants' climate and energy policy.

Cost-benefit analysis ("CBA") is a flawed economic framework for informing climate and energy policy, all too frequently biased against protecting the earth's climate and the needs of future generations. Some of the most ominous and important risks of climate change involve future risks and potential catastrophic and irreversible tipping points that may not be the most likely outcome but are nonetheless too likely to ignore. The framework of CBA, often applied to public policy evaluation today, relies on most likely, average, or expected (weighted-average) values for future risks and benefits. The CBA approach dismisses or devalues risks of extreme events and cannot accommodate climate impacts that become irreversible or unstoppable. An insurance framework provides a better way of thinking about catastrophic risks. Individuals who buy fire insurance or life insurance are typically insuring against events with annual probabilities of just a few tenths of a percent. Public policy modeled on insurance might focus on extreme risks which are about as likely as, or even more likely than, a residential fire or the death of a young parent (not impossible, but far from the most likely outcome), leading to a much more precautionary approach to climate and energy policy.

In addition to the issues of discounting and treatment of extreme risks, there are at least three fundamental problems with Defendants' application of CBA to climate and energy policy, all of which stem from the fundamental principle of CBA that requires a monetary value for every cost and every benefit – even those that are difficult or impossible to quantify.

- CBA is only meaningful if the estimates of costs and benefits are comparably complete – but this is almost never true in Defendants' evaluation of environmental policy. Costs of climate and environmental protection are generally matters of hardware and engineering estimates, which are easy to establish and meaningfully described in monetary terms. Benefits, in contrast, involve protection of life, health, nature, biodiversity, and other unmonetized, often unquantified, crucial values. Attempts at monetization of benefits are necessarily incomplete and approximate, to a much greater extent than on the cost side.
- Defendants' CBA analyses use the wrong information to measure the harm CO_2 emissions and unchecked climate change impose on individuals, families, and communities. When economists survey people to determine the value that the public places on environmental assets, they consider two perspectives. Willingness to pay ("WTP") asks what people would pay to avoid degradation of the asset, while willingness to accept ("WTA") asks what compensation people would accept for degradation. WTA would be appropriate if there is a right at issue – e.g., a property right or right to be free from harm – and polluters have to pay us to pollute; WTP would be appropriate if there is no such right, and we have to pay polluters to stop polluting. Both theory and experiment show that WTA is routinely higher than WTP, yet WTP has become the standard in CBA and climate economics, despite the fact that WTA would be more appropriate in the climate context.
- Since CBA demands prices for everything that matters, economists have invented prices for priceless values such as human life. These numbers do not play the same role as normal prices, however. Estimates such as $9 million per life saved do not imply that you can buy a life, or the right to kill someone, for $10 million. In the words of Immanuel Kant, some things we care about have a price, while others have a dignity. When evaluating policies and actions that encourage or discourage the development and use of fossil fuels, Defendants have not recognized that the benefits of climate protection include many things that have a dignity, which are literally priceless.

The conventional economic analyses relied upon by Defendants underrepresent costs of climate disruption. Within the existing methodology of cost-benefit-based federal government policy and the Obama Administration's SCC[1] calculations, there are specific data and analytical choices, which create additional biases against taking future climate risks seriously. In practice, economic assessment of climate policy has relied heavily on a handful of integrated assessment models ("IAMs"), namely DICE, FUND, and PAGE.[2] Inside each of these models, there is an assessment of the climate damages that are likely to occur as temperatures rise – the so-called "damage function". Calibration of the models' damage functions requires estimating the monetary value of damages at varying temperatures far above human historical experience.

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[1] The social cost of carbon ("SCC") refers to the present value of the cumulative damages caused by an additional ton of carbon dioxide ("CO_2") emissions.

[2] FUND (Climate Framework for Uncertainty, Negotiation and Distribution), DICE (Dynamic Integrated Climate-Economy), and PAGE (Policy Analysis of the Greenhouse Effect) are the three IAMs relied upon by the federal government in estimating the SCC.

These damage functions are misleading, in part, because they have often been based on very dated sources and imply very small aggregate damages from the first few degrees of warming. A National Academy of Sciences review (NAS 2017) has called for the use of newer sources, and proposed a number of such sources. Moreover, these damage functions exclude significant and severe climate impacts, such as ocean acidification and species and wildlife loss, and some of the biggest potential risks of climate change, such as climate-induced migration and conflict, because these impacts and risks are extremely difficult to quantify.

The result of all these biases is that Defendants' estimate of the SCC under the Obama Administration, a measure of the severity of climate damages and the urgency of policy responses, is much too low. The Obama Administration's final estimate (the August 2016 technical revision of their 2013 estimate), converted to 2017 dollars, was \$49 per ton of CO_2 in 2020, rising to \$81 in 2050. These government estimates of the SCC seriously understate the harm that continued CO_2 emissions will impose on these Youth Plaintiffs and future generations. Many other sources exploring small changes in assumptions, or addressing uncertainties in the calculation, have come up with much higher numbers: frequently above \$100 today, and in some cases above \$1,000 by 2050.

The costs of solving the climate crisis are falling rapidly. In contrast to the risks of catastrophic changes in the earth's climate system and the ever-increasing damages and costs from the present inaction of government that perpetuates climate pollution, the costs of renewable energy technologies to reduce emissions have been plunging downward in recent years. It is now much cheaper than anyone expected just a decade ago to substitute carbon-free energy for fossil fuels. Wind power is fully competitive with other power sources in suitably windy areas, such as the Plains states, and solar power and battery storage are moving rapidly in the same direction.

In my expert opinion, Defendants have made deliberate decisions with respect to the economic analyses underlying climate and energy policy decisions, placing these Youth Plaintiffs at substantial risk of suffering serious harm, without taking readily available measures to abate that risk, even though a reasonable government official in the circumstances would have appreciated the high degree of risk involved—making the consequences of Defendants' conduct obvious. By not taking such measures, Defendants engaged in conduct that caused and continues to cause injury to these Youth Plaintiffs and future generations. Defendants have dismissed or devalued the serious harm from climate change that young people and future generations will experience, resulting in a policy and practice that discriminates against Youth Plaintiffs and future generations. In other words, Defendants' longstanding climate and energy policy in the United States knowingly underrepresented costs of climate disruption and was deliberately indifferent to a substantial risk of serious harm to these Youth Plaintiffs and future generations, and therefore caused harm (and is causing harm) to these Youth Plaintiffs and future generations.

EXPERT OPINION

My purpose in this expert report is to identify biases in Defendants' conventional economic treatment of the costs and benefits of climate and energy policies. I find that there are multiple reasons why the costs of enabling and maintaining the fossil fuel energy system are often understated, while the costs of rapid emission reduction and climate recovery have often been exaggerated. As a result, conventional economic analysis conducted by Defendants has incorrectly suggested that the benefits of rapid emission reduction are not large enough to justify its costs. This biased conclusion and the policies based on it discriminate against young people and put the welfare of future generations at risk, by allowing climate change to proceed with too little effort to reduce emissions and impacts.

I. Discounting devalues future climate harm

Under Executive Order 12866 (1993), federal agencies are required to conduct a cost-benefit analysis of all economically significant policies and regulatory alternatives, comparing actions that could be taken to the alternative of no change in the status quo. This clearly applies to climate and energy policies. Defendants' attempts to perform cost-benefit analysis of climate and energy policies lead immediately to the dilemmas of discounting future costs and benefits – and in practice, have led to a devaluation of future climate harms, and discrimination against Youth Plaintiffs and future generations.

Conventional economic analyses, underlying Defendants' climate and energy policies, provide an inappropriate framework for analyzing such policies, when the costs and benefits occur across multiple generations. Any evaluation of climate and energy policy costs and benefits must weigh the costs of emission reduction incurred today and in the near term against benefits (i.e., avoided climate damages) that stretch much farther into the future. Conversely, such an evaluation involves weighing the short-term economic benefits of not reducing emissions against the long-term damages and costs of climate harm. Climate change is a very long-term problem, spanning multiple generations and lifetimes. A significant fraction of carbon dioxide ("CO_2") emissions remain in the atmosphere for more than a century, continuing to heat up the earth. Even if emissions were to stop tomorrow, the CO_2 already in the atmosphere would continue to heat up the oceans for decades to come, causing an ongoing rise in sea levels as well as other impacts. (Hansen et al. 2013, 2015)

In this context, Defendants' use of the common economic practice of discounting devalues the serious harm from climate change that young people and future generations will experience in their lifetimes. In particular, Defendants' use of improperly high discount rates allows the short-term economic benefits of maintaining a fossil fuel-based energy system, combined with inaction (or insufficient action) on emission reduction, to outweigh the very severe long-term impacts in its cost-benefit analysis.

The standard practice in climate economics, as in many other areas of economic analysis, is to convert – or "discount" – future costs and benefits into their present values in today's dollars. The present value of a future amount is the amount that would need to be placed in a savings account today, at a specified interest rate, in order to end up with the target amount in the future year. Note that the result is crucially dependent on the discount rate, as the interest rate is called in present value calculations. The larger the discount rate, the smaller the present value of any future amount. And the longer the time period, the greater the effect of changes in the discount rate.

These effects can be seen in **Table 1** below. At a discount rate of 1.5%, the present value of $1,000 a century from now is $226; at 3% it is $52, and at 6%, it is merely $3. Run the clock forward another century, and the present value of $1,000 two centuries from now is $51 at 1.5%, $3 at 3%, or just $0.01 at 6%.

In other words, at a low discount rate such as 1.5%, the present value of a cost or benefit 100 years from now is almost one-fourth of the future value. Even after 200 years, it retains some visibility, with a present value of $51. On the other hand, at a 6% discount rate, costs and benefits 100 or 200 years barely matter today: the present value of $1,000 drops to $3 in one century, and to just a penny in two centuries. At 6% it is hard to "see" the future; it shrinks by five orders of magnitude in 200 years. A 3% rate, intermediate between these extremes, still belittles the far future, reducing $1,000 to a present value of $3 in 200 years. Even at a rate of 3% – the rate used in Defendants' SCC under the Obama Administration – long-term climate consequences are largely hidden by discounting.[3]

Table 1. Present value of $1,000 payment in future years

	Discount rate		
Years from now	*1.5%*	*3%*	*6%*
100	$226	$52	$3
200	$51	$3	$0.01

Source: Author's calculations. Amounts, except $0.01, rounded to nearest dollar.

Discounting does have appropriate applications. Using a market interest rate, discounting is appropriate for private financial decisions within a single lifetime. The present value of the entire stream of payments due on a mortgage, car loan, or student loan, discounted at the rate at which one borrowed the money, is simply the amount that one borrowed. If one has the option of making an investment with a known payoff at a fixed future date, one would be well-advised to compare the present value of the payoff to the cost of the investment today, discounting the payoff at the interest rate available on savings accounts or other risk-free investments. If the present value of the payoff is less than the cost of the investment today, one would be better off leaving the money in the bank.

However, the same logic does not apply to intergenerational decisions about public goods. There is no one person who will experience and compare both costs of climate and energy policy incurred today and benefits of that policy experienced a century or more from now. And in any

[3] Defendant EPA recognizes the serious equity considerations of discounting in an intergenerational context in its Guidelines for Preparing Economic Analyses: "compounding interest over very long time horizons can have profound impacts on the intergenerational distribution of welfare. An extremely large benefit or cost realized far into the future has essentially a present value of zero, even when discounted at a low rate." (EPA 2010)

case, the benefits accrue to everyone worldwide, not solely to the descendants or fellow citizens of those who pay the costs today. Thus, as many economists would agree, the discount rate for climate analysis is at least in part an ethical decision, expressing our beliefs today about the value of the lives and wellbeing of young people and future generations, and the environment that we are leaving to them. If our impacts on future generations matter, then the appropriate discount rate for climate costs and benefits needs to be very low, probably near zero, an argument made effectively in the Stern Review (Stern 2007), and other sources.

There are two major approaches to calculating the discount rate for climate analysis, known as the descriptive and prescriptive approaches (for the classic presentation of these approaches, see Arrow, Cline *et al.* 1996). The descriptive approach asserts that the discount rate should be based on the rate of return on assets in financial markets; the prescriptive approach develops a discount rate from principles of economic theory, ultimately including normative judgments about the weight that should be given to the utility and welfare of future generations. Arguments can be made within either framework for adopting a near-zero discount rate.

The descriptive approach argues that rates of return in financial markets must be the relevant standard, even for long-term climate analyses, since we have a choice between investing in climate mitigation or investing the same amount in financial assets held in trust for future generations. The idea is that discounting future impacts at the market rate of return will tell us which choice is worth more for our descendants.

However, there are multiple rates of return on financial assets varying, among other characteristics, in their level of risk. Stock markets, with relatively high rates of risk, have high rates of return, often estimated at 6% or more in the long run. Use of such a high discount rate would amount to ignoring the far future, as suggested by Table 1 above. On the other hand, virtually risk-free assets such as government bonds have much lower rates of return, and risk-reducing assets such as insurance policies have negative rates of return (in every year when you do not file a claim for payment under the policy).

Investing in climate mitigation most closely resembles investing in risk-neutral or risk-reducing financial assets, in the face of uncertain but extreme climate risks. If expenditure on climate mitigation is virtually risk-free, or perhaps even risk-reducing, the descriptive approach might imply that its costs and benefits should be discounted at a risk-free or risk-reducing rate – perhaps 1.5% or less. As Table 1 demonstrates, a rate of 1.5% implies that far-future impacts remain significant in present value, and hence, should influence policymaking today.

The prescriptive approach, in contrast, separates the question of the appropriate discount rate into two parts. The first part is based on the assumption of rising income levels, and the second would apply if every generation had equal resources.[4] Regarding the first part: if we assume future generations will be richer than we are today, each additional dollar will be worth less to them than it is to us. One part of the prescriptive discount rate is therefore based on the projected

[4] Theoretical analysis identifies a third part based on the year-to-year variation (in technical terms, the variance) of growth rates. This is frequently omitted in applied analyses, since it is difficult to forecast the variance of growth rates, and numerical simulations suggest that this third term may be small.

growth rate of per capita consumption.[5] This part is generally less controversial among economists; however, it is important to note that by the same logic, if future generations are poorer than we are, due to climate-induced losses or any other cause, then the same amount of money is worth more to them than to us, so this part of the discount rate should become negative. This is an important but often overlooked argument for very low discount rates when evaluating the worst potential climate outcomes.

The second part of the discount rate under the prescriptive approach is the rate that would be appropriate if we knew that every generation would have the same per capita resources. This is often referred to as the rate of pure time preference. Its value is a matter of ethical judgment – and of unresolved controversy. A positive rate of pure time preference implies that we judge the contribution of future generations to social welfare to be less than ours. In effect, it represents discrimination by date of birth. Concern about the ethics of this judgment is not new in economics, as acknowledged by the Federal Government's Interagency Working Group ("IWG") on the Social Cost of Carbon: "Ramsey (1928), for example, has argued that it is 'ethically indefensible' to apply a positive pure rate of time preference to discount values across generations, and many agree with this view." (IWG 2010) The Stern Review argued that intergenerational equity – i.e. taking future generations seriously – requires a near-zero rate of pure time preference.[6] Combined with a low estimate of future growth rates, this led Stern to use a discount rate of 1.4%, close to the lowest rate shown in Table 1.

In summary, while debate continues on the merits of descriptive versus prescriptive approaches to discounting, and on the numerical values to be used, strong arguments have been made for a very low discount rate under either approach, if a cost-benefit analysis is performed at all. This is important because a very low discount rate is required in order to recognize the importance of climate impacts on future generations and their wellbeing, as suggested by Table 1.

Low values such as the Stern Review discount rate of 1.4% have been endorsed by many economists. For example, Nicholas Stern (2007), Geoffrey Heal (2009), Chris Hope (Johnson and Hope 2012), Martin Weitzman (1998), William Cline (2004), John Broome (1992), Paul Kelleher (2012), and myself (Ackerman and Finlayson 2006), among others, have all expressed opinions that the discount rate applied to long-term climate change damages should be lower than the 3% rate assumed by the IWG.

The Trump Administration's March 28, 2017 Executive Order rescinding the social cost of carbon ("SCC") continues the government practice of using high discount rates, which knowingly results in policies that are dismissive of future impacts. The Executive Order states: "when monetizing the value of changes in greenhouse gas emissions resulting from regulations, including with respect to the consideration of domestic versus international impacts and the

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[5] In a discount rate based on the prescriptive approach, the growth rate of consumption is multiplied by a parameter expressing how fast a fixed sum of money loses value to us as we become richer; in practice, that parameter is often assumed to be in the range of 1 to 3.

[6] A value of exactly zero leads to mathematical problems in formal modeling, and perhaps to implausibly strong implicit bias against the needs of the current generation. Stern (2007) proposed a rate of pure time preference of 0.1%, based on the assumption that we have an annual probability of 0.1% of destroying the human species. For Stern, all generations are of equal ethical importance if they exist, but next year's population is only 99.9% as important as this year's, due to its slightly lower probability of existence, and so on.

consideration of appropriate discount rates, agencies shall ensure, to the extent permitted by law, that any such estimates are consistent with the guidance contained in OMB Circular A-4 of September 17, 2003 (Regulatory Analysis)."[7] Circular A-4 describes the longstanding practice and policy in government regulatory analyses of assessing policies using both a 3% and a 7% discount rate. Whatever the historical merits of these rates, or the impacts in other arenas, in my opinion, they are far too high for sensible analysis of climate and energy policy. Even the use of a 3% discount rate – the rate used in Defendants' SCC under the Obama Administration – amounts to a dismissal of the impacts on future generations caused by present CO_2 emissions, compared to the lower rates used in the Stern Review and elsewhere. The discount rates mandated by the March 28, 2017 Executive Order continue to effectuate discrimination against future generations and children who will live into the second half of the century. By utilizing these inappropriately high discount rates, Defendants made a deliberate decision to be indifferent to the impacts on future generations caused by present CO_2 emissions, objectively knowing such impacts are substantially certain to result in continued and increased harm to the wellbeing and personal security of these Youth Plaintiffs and future generations.

II. Extreme risks and worst cases

Cost-benefit analysis requires a monetary value for every cost and every benefit – even those that are difficult or impossible to quantify. In the face of uncertainty, CBA requires an average, expected value, or most likely outcome. But the most worrisome consequences of climate change are the risks of catastrophic, irreversible changes for the worse, at times in the future that cannot be precisely predicted. Faced with catastrophic risks, most people do not think in terms of cost-benefit analysis; instead, they often buy insurance, even though they hope they will never need to use it. (This section of my report is based on the extended discussion of uncertainty and worst-case risks in Ackerman 2017.)

Consider the purchase of fire insurance. Public fire departments across the United States responded to 370,000 residential fires in 2013, while there were 133 million housing units in the country.[8] At that rate, the average housing unit has a fire large enough to report to the fire department once every 360 years. The annual number of fires is less than 0.3% of the number of housing units, so you have better than 99.7% confidence that you will not use your fire insurance next year. The most likely number of fires anyone will experience in a lifetime is zero.[9]

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[7] Presidential Executive Order on Promoting Energy Independence and Economic Growth, Sec. 5, March 28, 2017, https://www.whitehouse.gov/the-press-office/2017/03/28/presidential-executive-order-promoting-energy-independence-and-economi-1

[8] Fire data from National Fire Protection Association, "Fire Loss in the United States During 2013," http://www.nfpa.org/~/media/files/news-and-research/fire-statistics/overall-fire-statistics/fireloss2014.pdf?la=en. Housing unit data from the Census Bureau's American Housing Survey 2013, http://www.census.gov/programs-surveys/ahs/data/2013/national-summary-report-and-tables---ahs-2013.html.

[9] The National Fire Protection Agency similarly concluded that a household has a one in four chance of a fire reported to a fire department during an average lifetime. http://www.nfpa.org/research/reports-and-statistics/fires-by-property-type/residential/a-few-facts-at-the-household-level. If the annual probability of a fire is 0.3%, there is a one in four chance of a household having a fire every 95 years.

Much the same applies to life insurance, which is frequently purchased by young parents. The chance of dying next year is under 0.2% for the average American until age 40, and under 1% until age 60.[10] When homeowners buy fire insurance and young parents buy life insurance, they are expressing concern about potential personal disasters with probabilities of a few tenths of a percent per year.

Despite the fact that an insurance policy will lose money for the average policyholder, the worst-case outcome is bad enough to make it seem worthwhile. Even without knowing the exact probabilities of the ominous risks associated with climate change, future catastrophic outcomes are becoming more likely with every day we continue on a business-as-usual emissions trajectory, and delay serious emission reductions. Considering this, it makes sense to take catastrophic climate risks much more seriously, and to seek forms of collective self-insurance or protection against those risks (since there is no galactic insurance company that can write a policy covering damage to the only planetary climate we own).

In fact, the problem is more difficult than a decision to buy insurance, since we do not know the probabilities of worst-case outcomes. This leads to several unexpected results. For example, the Harvard economist Martin Weitzman (2009) proved what he called the "Dismal Theorem" of climate economics: the expected value of the benefits from emission reductions is literally infinite, essentially because worst-case scenarios could approach or include human extinction, and uncertainties regarding the probability of worst-case scenarios make it impossible to rule out those worst cases with sufficient confidence.[11]

Another strand of economic theory analyzes choices under deep uncertainty, where the range of possibilities is known, but nothing is known about their exact probabilities. Kenneth Arrow and Leonid Hurwicz, two well-known theorists who each won the Nobel Prize in economics, proved that if the possibilities are known but the probabilities are unknown, the ideal policy decision is based only on the best and worst possible outcomes (Arrow and Hurwicz 1972). Later work based on their result has shown if society is risk-averse or wants to keep its options open, only the worst case matters for choosing the best policy (Kelsey 1993, Gilboa and Scheidler 1989).

There is a secondary problem of determining whose forecasts of risks are credible, which may be particularly important in the age of Internet rumors and fake news. But the message of the Arrow-Hurwicz result and related later work is crucial for climate and energy policy: in the presence of inescapable uncertainties, policy should be based on the credible worst-case outcome. This, of course, entails rapid reduction in emissions to minimize the all-too-credible risks of abrupt, irreversible tipping points and catastrophic changes in the earth's climate. (Hansen et al. 2013, 2015) However, Defendants have not integrated these concerns about worst-case outcomes into their climate and energy policies and actions. The result is a theoretically unsound and dangerous bias favoring policies and actions that will increase the disproportionate climate damages and financial burden borne by these Youth Plaintiffs and future generations.

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[10] Based on all-cause mortality rates for 5-year age brackets, calculated from Arias (2014), Table B.

[11] See also discussion of Weitzman's Dismal Theorem in Ackerman (2017), pp. 127-129.

III. Why not cost-benefit analysis?

Since the beginning of the Reagan Administration, the Federal Government has been required to conduct a cost-benefit analysis ("CBA") for any significant regulatory action, to ensure that the action is worth doing.[12] In addition to the problems related to discounting and responding to extreme but uncertain risks, there are multiple, fundamental flaws in CBA as it has been practiced in Defendants' recent policy analysis. Here I will discuss three factors that make CBA inappropriate for climate analysis[13], and for many other environmental analyses as well:

- Asymmetry and incomplete monetization of benefits vs. costs;
- Use of willingness to pay (WTP) rather than willingness to accept (WTA) for valuations of environmental benefits and fundamental human rights; and
- "Pricing the priceless" – the morally ambiguous improvisations at the heart of the CBA process for human rights and environmental concerns.

A. Asymmetry and incompleteness

A hidden assumption of the cost-benefit comparison is that the calculations of costs and benefits are comparably complete. The calculation explicitly mimics the decision-making of a business comparing its costs and revenues; a product is profitable if and only if revenues exceed costs. Note that this calculation is biased and unreliable if either the costs or the revenues are incomplete. A business that compared complete costs to a partial accounting of revenues could miss profitable opportunities for investment. The opposite mistake, comparing partial costs to complete revenues, could lead to missing the signals that the company is losing money.

CBA of climate, energy, or other environmental policies is typically imbalanced and biased, providing a relatively complete accounting of costs, versus an incomplete and problematical accounting of benefits. On the cost side, environmental protection usually requires spending money on technologies and activities with well-defined, easily discovered market prices. For example, it may be possible to document the costs of emission reduction for the electric power system, transportation, and other sectors.

In contrast, the CBA process for climate and energy policy is very likely to have only a partial accounting and valuation of benefits.[14] Analysts may not recognize or include all the benefits of,

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[12] This requirement first appeared on February 17, 1981, in President Reagan's Executive Order 12291 and has been updated and continued by subsequent Executive Orders under more recent administrations.

[13] Defendant EPA has confirmed this conclusion in a 2008 report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, "Analyses of the effects of global change on human health and welfare and human systems." The report stated: "the economic approach [to human welfare], when interpreted as requiring a strict cost-benefit test, is not appropriate in all circumstances, and is viewed by some as controversial in the context of climate change [due to considerations of intergenerational equity and 'potential irreversible consequences']. Benefit cost analysis is one tool available to decision makers; in the context of climate change; other decision rules and tools, or other definitions of welfare, may be equally, or more relevant." (Sussman et al. 2008)

[14] The Office of Management and Budget in its 2003 guidance on Regulatory Analyses explains how this can be misleading: "When important benefits and costs cannot be expressed in monetary units, [CBA] is less useful, and it can even be misleading, because the calculation of

for example, the immense health benefits from the cleaner air that results from reduction of greenhouse gas emissions[15], or the multiple ecological services that forest protection can provide. The benefits of climate policy include protection of human life, health, many dimensions of the natural environment, biodiversity, ecosystem services, and other non-market values, such as aesthetic, cultural, and spiritual values. Prices can be deduced for some of these values, but not all; construction of artificial prices for human life and nature is a controversial process requiring significant time and expense. (This differs from market prices, which are available to all with little or no cost of acquiring information.) Additional problems with the construction of prices for priceless values are discussed in subsection C below.

Moreover, if the value of benefits cannot be estimated, Defendants' default value is zero. The adversarial context of CBA for government policy insists that if a monetized value for a non-market benefit cannot meet very high standards of rigor and certainty, it must be treated as if it were zero.[16] Analysts often try to describe in qualitative terms the benefits that they could not monetize, surrounding the numbers with extensive verbal accounts and multiple caveats. This prose can vanish in the policymaking process, which often acts as a "caveat-stripper": lose the words, keep the numbers. When this occurs, all information is lost about important benefits that the analysts identified but could not monetize. The result is an impoverished discourse about climate impacts, and an underestimate of the costs of climate harm and the benefits of emission reduction – contributing to the bias Defendants have shown toward policy decisions that perpetuate the harm to these Youth Plaintiffs and future generations.

Due to the problem of asymmetry and incompleteness in any CBA of climate and energy policy, we are left with a comparison of relatively complete costs and much more incomplete monetized benefits – and therefore a meaningless bottom line.

B. Who pays whom?

In the attempt to monetize non-market values, economists often end up surveying people about what those values are worth to them. It is worth noting at the outset that this method cannot measure the value to children of health and environmental protection.[17] For adults, economic value can be expressed in either of two ways: the most a person is willing to pay ("WTP") to obtain a benefit or item that they do not now have, or the minimum amount a person is willing to

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net benefits in such cases does not provide a full evaluation of all relevant benefits and costs." (OMB 2003).

[15] For a review of the rapidly expanding literature on health co-benefits of greenhouse gas emission reduction, see Gao et al. (2018).

[16] This is the effect, though not the stated intent, of the 1993 Supreme Court decision in *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. 579 (1993), setting extremely high standards for admissible evidence in regulatory analyses. As a result of *Daubert* and related standards, "pressures for ever-increasing documentation, review, and 'sound science' have been used to create unreasonable standards of evidence, interfering with the government's task of protecting the public." (Neff and Goldman 2005)

[17] The Office of Management and Budget in its 2003 guidance on regulatory analyses points out that the valuation of health and safety risks to children and infants "poses special challenges" stating that "[i]t is rarely feasible to measure a child's willingness to pay for health improvement." (OMB 2003).

accept ("WTA") for giving up a benefit or item that they currently have. Some simple economic theories have suggested that at the margin, the two should be the same.

However, both theory and experiment now confirm that there can be a wide gap between WTP and WTA measures, with WTA routinely larger than WTP. In theory, the gap between the two depends, in part, on whether there are any close substitutes available for the benefit in question, with very wide gaps possible for irreplaceable benefits (Hanemann 1991). In practice, one of the classic experiments of behavioral economics shows that even for ordinary, easily replaced items, WTA can be greater than, and often twice as large as, WTP.[18]

For CBA, economists have standardized on WTP measures of non-market values, perhaps because they are easier to calculate, or avoid problems of very high, even infinite valuations (Arrow, Solow *et al.* 1993). In any carefully framed and conducted study, no one's WTP can meaningfully exceed their income or assets, whereas people could logically demand much more than their own resources to accept environmental degradation. In fact, a refusal to accept environmental loss or loss of fundamental rights like personal security at any price, a legitimate, perhaps common, preference, could show up as an infinite WTA.

Climate mitigation benefits, or conversely losses from unchecked climate change, frequently involve irreplaceable gains or losses, where WTP and WTA would be expected to differ most widely. The choice between these two methods, in effect, is a question of rights and ownership: is the public buying natural assets or pollution abatement from polluters, at the WTP rate? This assumes that polluters own the environment and have the right to pollute. Or are polluters buying the opportunity to pollute from the public, at the WTA rate? The latter option assumes that the public owns the environment, and has the right to refuse pollution and be free from harm. Whatever the historical origins of the practice, standardization on WTP valuations in CBA amounts to asserting that the public has to buy nature from the polluters – a choice that lowers the value assigned to climate protection.

To make this more concrete, consider the plight of Levi, the youngest of the Youth Plaintiffs in this case, a child who lives on a barrier island off the coast of Florida. His WTP to avoid sea-level rise that would destroy his home and the surrounding beach is presumably limited to some fraction of his limited assets. His WTA value for destruction of his home and community could be very large, even infinite. Use of WTP reinforces inequality, since wealthier communities are willing to pay more, "justifying" greater protection for them. Moreover, the WTP approach implicitly asserts that Levi and his neighbors may have to buy the right to continue living where they do, from polluters who would profit by contributing to their community's destruction.

C. Pricing the priceless

Many of the benefits of climate and environmental protection are difficult to value because they consist of saving human lives, preventing extinction of species, and other non-marketable goals.

[18] A group of college students were randomly given either a mass-produced coffee mug decorated with their college insignia, or an amount of money equal to the market price of the mug, and then invited to trade with each other. WTA, i.e. the price at which those who were given mugs were willing to sell them, averaged about twice as much as WTP, the amount that those who received cash would pay for a mug. This general pattern has reportedly been found in a number of other settings (Kahneman 2011).

Since air pollution kills many people, the value of each life saved is crucial to valuation of the benefits of pollution reduction. For CBA purposes, it has become common to assume values around $9 million per life saved (often called the "value of a statistical life", or VSL) in the United States. Regulations that save lives at less than $9 million apiece pass a cost benefit test; those that cost more than $9 million per saved life fail the test.

This monetization of a human life at $9 million does not mean, however, that you can buy the right to kill someone for $10 million. Even stranger is the alternative, favored by some analysts, of individually valuing each year of life saved; since everyone will eventually die, the argument goes, all we are doing is saving life-years. But assigning a fixed dollar value per saved life-year suggests that, contrary to all major ethical and religious beliefs, it is a lesser crime to kill an older person.

The urge to monetization has mis-framed the question of the value of life. Figures such as $9 million per life saved are built up from small risks, such as $9 WTP to avoid a one-in-a-million risk of death. But imagine one million people, all facing a one-in-a-million risk of death. On average, all but one of them will survive, although experiencing that $9 risk. Those risks to the 999,999 survivors total almost $9 million in value, amounting, in round numbers to the value of one "statistical life." One of the million people, on average, will not survive; that person's much worse experience is not meaningfully addressed by the $9 WTP value nor the $9 million VSL.

WTP to avoid small fractional risks of premature death can, arguably, place a value on risks experienced by those who survive. It cannot, however, value life itself, which has no meaningful monetary price. As the philosopher Immanuel Kant said long ago, some things have a price, while other things have a dignity (Kant 2005 [1785]).

The same is true of the natural world and the valuation of non-human species. A study, some years ago, found that U.S. households were willing to pay a total of $18 billion to prevent the extinction of humpback whales.[19] This does not mean that anyone would have welcomed an offer of $20 billion for the opportunity to hunt humpback whales to extinction. Rather, the $18 billion WTP value was an inarticulate statement of the fact that people value the survival of whales very highly; the number itself has no real meaning. Whales, too, as sentient beings and thus proper objects of our moral concern, have a dignity, and not a price.

A final, jarring example of an attempt to monetize the priceless came in a Department of Justice study, which chose to conduct a CBA of the Prison Rape Elimination Act. The study, which was clearly not required by law, has been praised by prominent CBA advocates (Sunstein 2014). A centerpiece of the study was the value of an avoided rape, reportedly $310,000. Resembling the problems with the value of a statistical life, the number apparently came from a survey asking people how much they would pay to live in a neighborhood with fewer rapes. Once again, it is a value of avoiding small risks experienced by those who do not suffer the horrific event being evaluated. The assigned price again illustrates the poverty of thinking underlying traditional CBA. Freedom from violence also has a dignity, and that too should not be ignored simply because it is not susceptible to accurate pricing.

Climate mitigation is full of parallel cases: policies that will protect human lives, species at risk, public trust resources, and other priceless values such as these Youth Plaintiffs' fundamental

[19] See the account in Ackerman and Heinzerling (2004).

constitutional rights. However, these priceless benefits from climate mitigation are deliberately not reflected in Defendants' climate and energy policies or actions. The invented imperative of cost-benefit analysis neither justifies nor renders rational the assignment of prices to human lives and other matters of intrinsic concern. They are worth protecting because of their dignity, not their invented prices. But if all you have is a calculator, everything looks like a number.

IV. The social cost of carbon: Getting the numbers wrong

Economic analysis of climate damages is often summarized in estimates of the social cost of carbon ("SCC"), defined as the present value of the present and future damages caused by emission of one additional ton of CO_2. The previous sections of this expert report identified many reasons why such numerical estimates are likely to be incomplete and understate the true extent of climate damages. This section explores recent calculations of the SCC in greater detail, focusing on the models used in the federal Interagency Working Group ("IWG") calculations in 2010 and 2013 (IWG 2010, 2016).

Economic theory describes environmental damages as negative externalities, or costs that market transactions impose on uninvolved third parties. For example, the Plaintiffs in this case, and others of their generation and their descendants, were neither the buyers nor the sellers of fossil fuels that caused most of the harm to the climate. The theoretical remedy, known since the work of Arthur Pigou (1920), is that the costs of externalities should be internalized, or included in the price of activities that cause emissions. This would force buyers and sellers to recognize the true costs of emissions, and would decrease demand.

If the SCC were an accurate measure of climate damages, then it could be incorporated into prices of fossil fuels (and other sources of CO_2), sending a strong price signal about the need to cut back on these fuels and their associated emissions. In practice, this has never been done for the economy as a whole, although many Obama Administration regulatory analyses included the IWG's SCC estimate for the value of carbon emissions. For example, this added to the calculated benefits of vehicle fuel economy standards, since those standards (modestly) reduced fuel use and vehicle emissions. (Conversely, the Trump Administration's abandonment of the SCC means that there is a complete lack of internalization of climate externalities; continuing the same example, the calculated benefits of vehicle fuel economy standards would now be lower, with the cost of carbon emissions effectively valued at zero.)

The IWG's analyses averaged the results from slightly modified versions of three integrated assessment models ("IAMs"), known as DICE, PAGE, and FUND. IAMs offer "integrated" calculations of the future evolution of the global economy and climate, at a very simplified level. The three chosen models are perhaps the best-known IAMs, but not necessarily the most accurate, and certainly not the most detailed. A 2017 review by the National Academy of Sciences (NAS 2017) identifies numerous weaknesses in these three models, and makes many suggestions for improvement.

A. Damage functions and dated research

IAMs rely on a "damage function" – a mathematical representation of the damages expected as temperatures and sea levels rise. The creation and validation of a damage function is difficult, as it describes climate-related losses expected under conditions that are outside our historical experience. Nonetheless, there is a certain amount of research bearing on this subject. As the

National Academy of Sciences review (NAS 2017) points out, the three IAMs used by the IWG, namely DICE, PAGE, and FUND, rely on dated research.

FUND, the one of the three models with the most disaggregated damage calculations, relies heavily on estimates of climate damage from the 1990s. According to NAS (2017), FUND version 3.8, used in the 2013 IWG calculation, relied on 27 sources for its damage estimates – 18 of them published in the 1990s.[20] This is potentially important because FUND consistently produces the lowest estimate of climate damages among the three models relied on by the IWG, reducing the SCC (which is calculated as a three-model average). FUND's agricultural estimates, drawing on 1990s research, project net global benefits from the first few degrees of warming, offsetting damages in other sectors (Ackerman and Munitz 2012, 2016). Newer research is available, often projecting a more ominous picture of damages in agriculture from near-term climate changes. Indeed, the NAS review offers a list of 30 sources, published from 2007 to 2016, which could be used to update climate damage estimates relied on by FUND.[21]

DICE and PAGE also understate the cost of climate damages, but offer less detailed development of their damage estimates. The latest version of DICE (newer than the one used by the IWG), DICE-2016R, bases its damage estimates on a recent (apparently unpublished) literature review by William Nordhaus and a coauthor. According to Nordhaus, the economist who developed DICE, the damage function in DICE-2016R implies global climate damages equal to 2.1% of income at 3°C of warming, and 8.5% of income at 6°C (Nordhaus 2017, supplementary information). At recent U.S. growth rates, this means that 3°C of warming would cause damages equal to the loss of less than 18 months of economic growth, equivalent to taking us back to the economy of early 2017, while the damages from 6°C would be equivalent to losing less than 5 years of growth – the same as busting us all the way back to 2013. At China's much faster growth rates, even 6°C would cause losses of less than 18 months of growth, sending the Chinese economy back to early 2017.

Whatever the source of the DICE damage estimates, they appear to trivialize the risks of significant warming. In his recent writing, Nordhaus has emphasized unquantifiable impacts and risks of irreversible extreme events (Nordhaus 2013). But the damage function in his model lags behind his qualitative descriptions of climate risk, helping to perpetuate an understatement of the cost of emissions.

Defendants, through the IWG (in both 2010 and later revisions), recognized the many sources of uncertainty and important limitations of the IAMs relied upon for the SCC. The IWG admitted that the IAMs do not include "all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature" due to a "lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research." (IWG 2010, 2016) Importantly, the IWG recognized its complete inability to monetize, and thus omission, of significant and severe climate impacts: "even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)" (IWG 2010)

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[20] See NAS (2017), Table 5.2. Two of the nine "newer" sources for FUND 3.8 were review articles by one of FUND's developers, published in 2002.
[21] NAS (2017), Table 5.3.

In addition to the complete omission of these severe damages from the SCC estimates, the IWG noted other sources of uncertainty that have not yet been fully quantified in the IAM's, and thus Defendants' SCC estimate under the Obama Administration, including potential catastrophic damages due to "tipping points" in Earth systems with "potentially severe social and economic consequences" and "inter-sectoral and inter-regional interactions, including global security impacts of high-end warming." (IWG 2010, 2016)

The IWG also explained the risks of using conventional economic analysis and assumptions in the context of climate change: "The three IAMs used here assume that it is possible to compensate for the economic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation. . . . For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace." (IWG 2010)

B. Published estimates of the SCC

There is a wide range of published estimates of the SCC, many of them much higher than the estimates the IWG proposed for use in U.S. government cost-benefit analyses. The federal IWG's final revision, in August 2016, put the SCC, in 2017 dollars, at $42 per metric ton of CO_2 in 2015, rising to $49 for emissions in 2020 and $81 in 2050 (IWG 2016).[22] The IWG offered two variants on its own work that implied much higher values: reducing the discount rate from 3% to 2.5% would raise the SCC by about 40%, while using much higher climate sensitivity (implying much greater long-term warming from the same level of greenhouse gases in the atmosphere), at a 3% discount rate, would roughly triple the SCC.[23]

Several SCC calculations have been done with DICE, after making minor modifications to the model. In my own work, coauthored with Elizabeth A. Stanton, we explored combinations of four changes to DICE: lowering the discount rate to 1.5%, adopting much higher climate sensitivity, and making two adjustments to the DICE damage function, one of which was based on Martin Weitzman's suggestion of 50% loss of global income at 6°C and 99% loss at 12°C (Ackerman and Stanton 2012). With four independent changes to the DICE defaults, we produced 16 variants on the SCC. Our estimates for the SCC in 2050, converted to 2017 dollars, ranged from $75 to $1,824 per metric ton of CO_2. The point is not that we know the SCC will be over $1,800 in 2050; rather, we do not know with any reasonable level of confidence that the

[22] The basic modeling was done by the IWG twice, in 2010 and 2013. Several technical updates made minor corrections to the 2013 estimate after publication. The results were published in 2007 dollars, and have been multiplied by 1.177 to convert to 2017 dollars, based on the increase in the Consumer Price Index. The figures here are the so-called "central estimate", based on a 3% discount rate and median climate sensitivity.

[23] Results were not provided for the combination of these two innovations. Another set of IWG calculations raised the discount rate to 5%, resulting in an SCC of about one-third of the "central estimate". For the reasons I have explained above, estimates of the SCC using a discount rate this large are not appropriate for Defendants' climate and energy policies and actions.

SCC will not be that high. The range of uncertainty in the DICE SCC, considering only the four changes we examined, is more than twenty-fold (i.e., $1,824 is more than 20 times $75).

In Nordhaus' latest work (Nordhaus 2017), using a newer version of DICE than used in my research, or in the IWG calculations, he finds that in his most severely climate-constrained scenario, the SCC rises from $207 in 2015 to $1,129 in 2050.[24] For another analysis that finds that revision of the DICE damage function can cause a large increase in the estimated SCC, see Howard and Sterner (2017). Yet another analysis, using an older version of DICE, modified to include the risks of multiple tipping-point catastrophes, found that those risks increased the SCC to $130 in 2017 dollars (Cai et al. 2016).

Chris Hope, the developer of the PAGE model, has also estimated the SCC to be higher than the government's calculation. Hope has published an analysis of the SCC implied by his PAGE09 model (Hope 2011). His preferred estimate, using his default values, is equivalent to $151 in 2017 dollars.[25] PAGE has always been the source of the highest SCC estimates in the IWG process, but the estimate using Hope's preferred values is even higher than the IWG's modified PAGE values.

Surveys of scientists and economists show broad agreement that the IWG's SCC is too low. Robert Pindyck (2016) surveyed several hundred climate experts, both economists and scientists, and concludes that their consensus estimate, for the SCC today, is about $200 for the entire sample, or $80 for the subset who expressed high confidence in their estimates. Estimates from scientists were, on average, much higher than from economists. In another survey of experts on the economics of climate change, over half of the respondents believed that the SCC should be higher than the IWG estimate, and only 8% of respondents believed it should be less (Howard and Sylvan 2015).

A meta-analysis (van den Bergh and Botzen 2014), exploring risks and uncertainties left out of the standard IAM calculations, concluded that the SCC should be at least $125, and perhaps much higher. A modification of DICE, incorporating new research showing that temperature increases lead to slower economic growth, implies a SCC more than six times the standard DICE estimate today, and rising rapidly beyond that over the next few decades (Moore and Diaz 2015).

In short, there is an enormous range of SCC estimates, including values far above the IWG estimates, that have appeared in the recent climate economics literature. The IWG itself recognized the inherent uncertainty about the value of the SCC and concluded in 2016 that due to the many sources of uncertainty and important limitations in the IAMs (discussed above), the SCC "estimates are likely conservative." The IWG quotes from the IPCC Fourth Assessment Report's conclusion that the SCC "estimates 'very likely . . . underestimate the damage costs' due to omitted impacts. Since then, the peer-reviewed literature has continued to support this conclusion, as noted in the IPCC Fifth Assessment report." (IWG 2016) There is nothing

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[24] These numbers are for his scenario constrained to stay under 2.5°C of warming. The higher SCC results from the constraint, not from a different damage function. Results in Nordhaus (2017) were published in 2010 dollars, and have been converted to 2017 dollars by multiplying by 1.122.
[25] His published value of $106 for 2010, in 2000 dollars, was multiplied by 1.427 to convert to 2017 dollars.

approaching a consensus about the SCC – which is another way of saying that the exact damages expected from climate change remain uncertain, but potentially very serious.

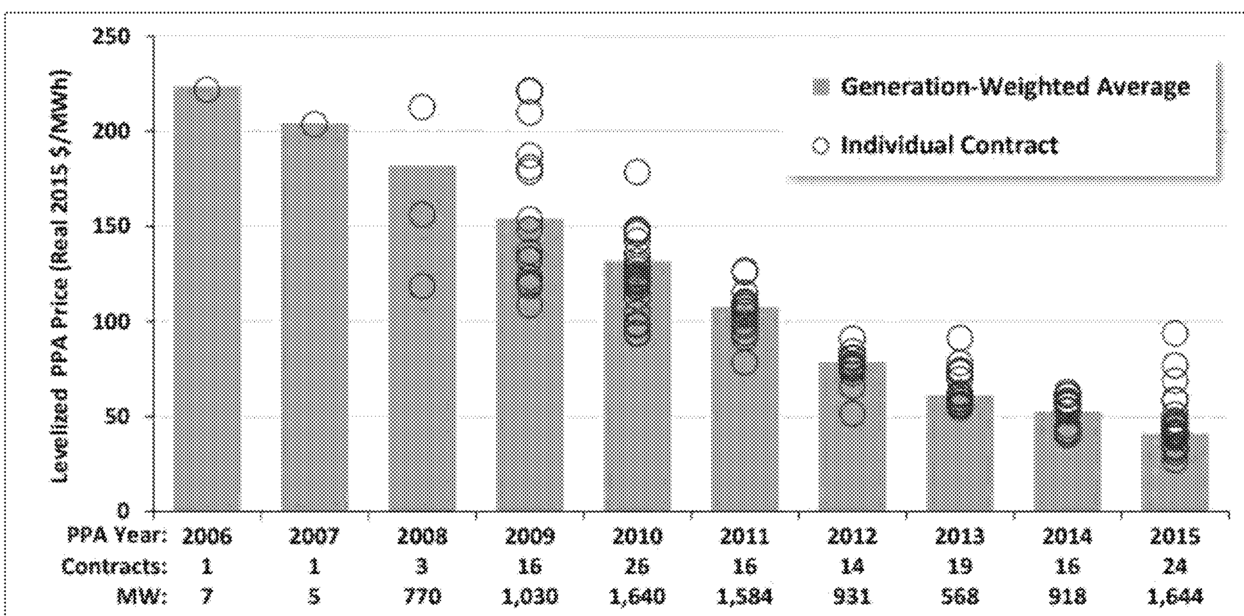
The preceding paragraphs also suggest it would be reasonable to conclude that the actual SCC is several times greater than the Obama Administration's admittedly conservative and incomplete estimates of the SCC. Those estimates therefore provided a knowingly biased basis for Defendants' policies and actions favoring the burning of fossil fuels and imposing the costs on these Youth Plaintiffs and future generations. Actions by the Trump Administration to abandon consideration of the SCC deliberately exacerbate the bias.

V. The low cost of climate protection

The costs of climate impacts are high and increasing, while the costs of climate protection technologies are low and decreasing. The uncertainties surrounding climate damages (and hence the benefits of avoiding those damages) involve risks of disastrously worse-than-expected outcomes, which are difficult to rule out with a comfortable level of confidence. In contrast, the uncertainties surrounding the costs of emissions are often a source of optimism: prices for clean energy, especially solar power, have dropped precipitously in recent years.

The levelized prices in purchased power agreements ("PPAs") for utility-scale photovoltaic installations are falling, as shown in **Figure 1**. These are the prices that independent solar power producers receive when they sign long-term contracts to provide power to local utilities, including the effects of subsidies.[26]

Figure 1. Levelized photovoltaic PPA prices by contract vintage



Source: Mark Bolinger and Joachim Seel, "Utility-Scale Solar 2015" (Lawrence Berkeley National Laboratory, 2016), p.33.

[26] "Levelized" means these are the average present value prices over the lifetime of the contract. They were calculated using a 7% discount rate.

The price of solar electricity generation is falling precipitously. As recently as 2006-07, large-scale solar installations were rare, and the few large-scale solar installations that existed were receiving over $200 per MWh – or $0.20 per kwh. By 2014-15, utility-scale contracts were numerous, with average payments of $50 per MWh ($0.05 per kwh) or less – that is, less than one-fourth of the rate just eight years earlier. (Other measures of costs of solar power yield different numbers, but the downward trend remains unexpectedly strong, and encouraging.) Ten years ago, it would have seemed foolishly optimistic to predict such a rapid decline in renewable energy costs absent government leadership and support. Yet it has happened: wind and solar power are now important resources in state energy planning. Indeed, wind power plays an even larger role than solar power. In two states, Iowa and South Dakota, wind was the source of more than 30% of total electricity generation in 2016, and 12 other states exceeded 10%.[27]

There are now multiple studies – based on costs of renewable energy that are only a few years out of date – showing that 80% reduction in emissions by 2050 can be achieved with moderate, if any, increases in energy costs, without assuming any SCC or other internalization of climate damages (Ackerman et al. 2015, Williams, Haley, *et al.* 2015, White House CEQ 2016). This target requires doing more than switching to clean sources of electricity: emissions from electricity generation were only 29% of total U.S. carbon emissions in 2015.[28] In addition to introducing nearly emission-free electricity, the 80% reduction target requires electrifying other fossil fuel-using sectors such as light-duty vehicles (cars, pickups, and SUVs), residential and commercial heating, and others.

To achieve the even greater reduction in emissions, close to 100% by 2050, which Hansen et al. (2013) found to be necessary to achieve climate stability, even more must be done. Additional sectors such as heavy-duty vehicles (trucks and buses), agriculture, and industry must also be converted to zero-carbon fuels and technologies. Technologies that reduce emissions in these sectors are also progressing rapidly. For example, through the Department of Energy's "SuperTruck" program, major truck manufacturers have already produced tractor-trailer prototypes using half the fuel of conventional models.[29] This and other advances provide grounds for optimism about completing the transition to a carbon-free economy – a goal that is urgent to complete as rapidly as possible. The urgency with which Defendants treat that goal is ultimately a judgment about how to value today's youngest generation and those who will follow them.

CONCLUSION AND RECOMMENDATIONS

My expert report identifies deliberate biases in Defendants' use of the conventional economic treatment of the costs and benefits of climate policies, including the federal government's development of an estimated social cost of carbon as a measure of expected climate damages. I find that there are multiple reasons why Defendants use of standard economic analyses has materially understated the costs of business as usual, while the costs of taking action to mitigate

[27] American Wind Energy Association, "U.S. wind generation reached 5.5% of the grid in 2016", March 6, 2017, http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=9999.
[28] Data on emissions from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.
[29] Department of Energy, "SuperTruck leading the way in efficiency for heavy duty, long haul vehicles", June 27, 2016, https://energy.gov/eere/articles/supertruck-leading-way-efficiency-heavy-duty-long-haul-vehicles.

climate harm have often been exaggerated. As a result, Defendants' economic analyses underestimate and devalue the serious harm from climate change that young people and future generations will experience, allowing the short-term economic benefits of not regulating (or insufficient regulations) to outweigh extremely severe long-term impacts in its cost-benefit analysis. This biased result does not reflect the reality that continuing to burn fossil fuels and increase CO_2 emissions will be extremely harmful to these Youth Plaintiffs and future generations and that this harm far exceeds the costs of implementing measures that would prevent this harm. Accordingly, Defendants have been on notice for some time that their policies pose a substantial risk of serious harm to these Youth Plaintiffs and future generations, and they continue to be deliberately indifferent to that risk.

Defendants are unreasonably placing the welfare of our nation's youngest and future generations at risk, by allowing climate change to proceed with too little effort to reduce emissions and their potentially catastrophic and irreversible impacts. My grandchildren, and the Plaintiffs in this case, as well as the generations that will follow them, deserve a climate and environment as stable and supportive of human and natural life as the one I grew up in. To that end, Defendants should be directed to rapidly accelerate efforts to reduce greenhouse gas emissions, and to stop supporting and promoting fossil fuel energy, supported by the corrected and updated economic analysis that I have described in this expert report.

Signed this 13th day of April, 2018 in Cambridge, Massachusetts.

Frank Ackerman

Frank Ackerman

Attachment 8

EXPERT REPORT
OF
JOSEPH E. STIGLITZ, PH.D.

University Professor, Columbia University

Kelsey Cascadia Rose Juliana; Xiuhtezcatl Tonatiuh M.,
through his Guardian Tamara Roske-Martinez; et al.,
Plaintiffs,

v.

The United States of America; Donald Trump,
in his official capacity as President of the United States; et al.,
Defendants.

IN THE UNITED STATES DISTRICT COURT
DISTRICT OF OREGON

(Case No.: 6:15-cv-01517-TC)

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TABLE OF ACRONYMS AND ABBREVIATIONS

C:	Celsius
CAFE:	Corporate Average Fuel Economy
CAD:	Canadian Dollar
CBO:	Congressional Budget Office
CO_2:	carbon dioxide
CPI:	consumer price index
EPA:	U.S. Environmental Protection Agency
GDP:	gross domestic product
GHGs:	greenhouse gases
IMF:	International Monetary Fund
IPCC:	Intergovernmental Panel on Climate Change
NASA:	National Aeronautics and Space Administration
NOAA:	National Oceanic and Atmospheric Administration
OECD:	Organisation for Economic Co-operation and Development
OMB:	Office of Management and Budget
ppm:	parts per million
R&D:	research and development
USGCRP:	U.S. Global Change Research Program

I. QUALIFICATIONS AND PROFESSIONAL BACKGROUND

1. I am one of sixteen University Professors at Columbia University with joint appointments in the Faculty of Arts and Sciences (Department of Economics), the Graduate School of Business (Department of Finance), and the School of International and Public Affairs. Prior to assuming this position, I held professorships at Stanford University, Yale University, Princeton University, and the University of Oxford, where I taught a wide variety of graduate and undergraduate courses in economics and finance. I received my Ph.D. in Economics from MIT in 1967.

2. Over the course of my career I have published hundreds of peer-reviewed articles, written or edited more than 50 academic and popular books, testified several times before Congress, and written numerous opinion pieces for newspapers and magazines. My publications and research have extended into many different areas, including macroeconomics and monetary theory, development economics and trade theory, public and corporate finance, industrial organization and rural organization, welfare economics, and income and wealth distribution, many of which are germane to this case. Oxford University Press is in the process of publishing a six-volume set based on my research, *Selected Works of Joseph E. Stiglitz*. The first two volumes have been published and are entitled *Information and Economic Analysis: Basic Principles and Information* and *Economic Analysis: Applications to Capital, Labor, and Products Markets*.

3. Public economics and public finance, which study how governments raise funds and make expenditures, have been major pillars of my academic work. I served as a co-editor of the *Journal of Public Economics*, the leading economics journal dealing with matters of taxation and public economics, and have published broadly in this area. My textbook, *Economics of the Public Sector*, is a leading text first published in 1986 with the most-recent version released in 2015. Another of my books, *Lectures on Public Economics*, published in 1980 and reprinted in 2015 with a new introduction, has been widely translated. Many of my popular texts, including my recent books *The Great Divide* and *The Price of Inequality*, published in 2015 and 2012, respectively, critically examine our public institutions, and comment on public finance and public economics generally.

4. Environmental economics and economic policy around natural resources has been another focus of my academic and professional work. I was one of the lead authors of the 1995 Report of the Intergovernmental Panel on Climate Change, which shared the 2007 Nobel Peace Prize with former Vice President Gore. I was co-chair of the High-Level Commission on Carbon Prices (we released our report in May 2017). I was also involved in environmental economic policy during my time on the Council of Economic Advisors, where one of my responsibilities was evaluating, designing, and implementing public policies that affect the environment, and while Chief Economist of the World Bank, where one of my responsibilities was evaluating and designing environmentally sustainable economic policies. I have also published many peer-reviewed articles that examine how we treat externalities (e.g., pollution) and public goods (e.g., the environment).

5. I have received numerous fellowships and honors over my career. In 2001, I was awarded the Nobel Memorial Prize in Economics for my work on Information Economics. This work includes the study of how information asymmetries affect economic behavior, the determination of the conditions under which efficient sharing of risk occurs, and the economics of financial markets, which are directly relevant to this case. In 1979, I was awarded the John Bates Clark Medal by the American Economic Association, given biennially to the economist under 40 who has made the most significant contribution to economics.[1]

6. I was the founding editor of the *Journal of Economic Perspectives*. I have served (or am currently serving) on the Editorial Board of numerous journals, including *The Economists' Voice*, the *Journal of Globalization and Development,* the *World Bank Economic Review*, the *Journal of Public Economics*, the *American Economic Review*, the *Journal of Economic Theory*, *The Review of Industrial Organization*, *Managerial and Decision Economics*, *Energy Economics*, the *Review of Economic Design*, and the *Review of Economic Studies*.

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[1] The John Bates Clark Medal has been given annually since 2009.

7. I served as President of the International Economic Association from 2011–2014 and as President of the Eastern Economic Association in 2008. I also served as Vice President of the American Economic Association in 1985.

8. I have received more than 40 honorary degrees, and have received awards from foreign governments, including the Legion of Honor from France. I have also been elected to numerous academic and scientific societies in the United States and abroad, including the National Academy of Sciences, the Royal Society, the American Academy of Arts and Sciences, the American Philosophical Society, and the British Academy. In 2011, *Time* magazine named me to their *Time 100* list as one of the 100 most influential people in the world.

9. From 1993 to 1997, I served as a member of President Clinton's Council of Economic Advisers, and from 1995 to 1997, as Chairman of the Council and a member of the President's Cabinet. As Chairman and Cabinet Member, I was heavily involved in formulating fiscal policy, sustainable economic policies (including environmental economic policies), financial sector regulation and banking policy, and coordinating policy with the U.S. Treasury.

10. From 1997 to 2000, I served as Chief Economist and Senior Vice President of the World Bank, in which capacity I had the responsibility of advising countries around the world on the design of fiscal, tax, and monetary policies, competition policies, sustainable economic policies (including those regarding natural resources and the environment), intellectual property regimes, financial regulations, and trade policy.

11. I have served or am serving currently on many commissions and advisory committees addressing a myriad of economic policy issues, both in the U.S. and abroad, including the Joint CFTC-SEC Advisory Committee on Emerging Regulatory Issues, the United Nations' International Labour Organization World Commission on the Social Dimensions of Globalization, the High Level Panel of the African Development Bank, and the Economic Advisory Panel in South Africa.

12. At the behest of the President of the General Assembly of the United Nations, I served as Chair of the Commission of Experts on Reforms of the International Monetary and Financial System, to review the workings of the global financial system in the wake of

the 2008 economic crisis and suggest steps for U.N. member states to secure a sustainable economic future. Our final report was published in September 2009. In addition, I was appointed President of the Commission on the Measurement of Economic Performance and Social Progress by President Sarkozy of France, in 2008. This commission was formed to consider flaws in traditional macroeconomic indicators measuring economic performance and social progress and consider what might be the more relevant metrics, which are relevant to this case. Our final report was released in September 2009.

13. In 2000, I founded the Initiative for Policy Dialogue, for which I continue to serve as co-President. The Initiative for Policy Dialogue is a global network of academics and practitioners to enhance democratic processes for decision-making in developing countries. I am also Co-Chair of the High-Level Expert Group on the Measurement of Economic Performance and Social Progress, Organisation for Economic Co-operation and Development (OECD) and the Chief Economist of, and a Senior Fellow at, the Roosevelt Institute.

14. Previously, I served as Chair of the Management Board at the Brooks World Poverty Institute at the University of Manchester, on the Board of Trustees of Amherst College, my undergraduate *alma mater*, and as Co-Chair of Columbia University's Committee on Global Thought.

15. I have provided expert testimony in various fora throughout the United States, and before foreign courts and international tribunals. I have submitted *amicus curiae* briefs before the Supreme Court of the United States and before U.S. Circuit Courts of Appeal. My expert testimonies have related broadly to financial markets and derivatives, taxes, antitrust and competition, patent enforcement, and public interest generally (e.g., promotion of efficiency and/or minimization of welfare costs). I have also offered testimony regarding environmental economics, specifically, around offshore drilling.

16. My curriculum vitae, which provides more details of my qualifications, including a list of my publications, is attached as **Exhibit A**. **Exhibit B** contains a list of my previous expert testimony within the last five years. The materials that I, and volunteers supporting me at my direction, considered in preparing this report are cited in the footnotes and listed in **Exhibit C**.

17. I am working *pro bono* to prepare this expert report. My usual rate for work in litigation matters is $2,000 per hour, which is the rate I will charge if another party seeks discovery under Federal Rule 26(b). I have no present or intended financial interest in the outcome of this matter. My work in this matter is ongoing, and I reserve the right to revise or augment the opinions set forth in this report should additional relevant information become available to me, or as I perform further analysis.

II. ASSIGNMENT AND SUMMARY OF CONCLUSIONS

18. Julia Olson and Philip Gregory, counsel for Plaintiffs in this matter, have asked me to provide my expert opinion on the economics of transitioning to a non-fossil fuel economy.[2] In particular, I have been asked: (a) to analyze from an economic perspective how climate change will harm the Youth Plaintiffs (and Affected Children) if Defendants continue to pursue policies that perpetuate a fossil-fuel-based energy system and defer action to mitigate climate change; and (b) to assess the economic benefits of transitioning to a non-fossil-fuel economy now rather than later. The opinions expressed in this report are my own. All opinions expressed herein are to a reasonable degree of scientific certainty, unless otherwise specifically stated.

19. I have formed four primary conclusions in this case, the bases for which are set forth more fully below:

    a. Scientific evidence shows further incremental increases in global temperature will lead to disproportionately greater costs imposed on our society. This has important consequences for how Defendants' actions harm the Youth Plaintiffs and Affected Children more generally. Continuation of the national fossil fuel-based energy system by Defendants is causing imminent, significant, and irreparable harm to the Youth Plaintiffs and Affected Children more generally. This kind of environmental harm, by its nature, cannot be adequately remedied by money damages and is often permanent or at least of long duration, i.e., irreparable. There is a point at which, once this harm occurs, it cannot be undone at any reasonable cost or in any reasonable period of time. Based on the best available science, our country is close to approaching that point.[3]

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2 I understand that the plaintiffs in this litigation are young people, who I will refer to as the "Youth Plaintiffs." However, my analysis also looks at the impact on other young people who are not named plaintiffs (and as-yet-unborn youth, the so-called future generations), but are just as (or even more) affected, whom I collectively refer to as "Affected Children."

3 This is a global problem. However, as I discuss below in Section V.B, the U.S. is a significant contributor to GHG emissions, and so actions by the U.S., have a significant impact on these global outcomes.

b. Defendants' continuing support and perpetuation of a national fossil fuel-based energy system and continuing delay in addressing climate change is saddling and will continue to saddle Youth Plaintiffs with an enormous cost burden, as well as tremendous risks, which is causing substantial harm to the economic and personal well-being and security of Youth Plaintiffs. These costs and risks will be borne over each ensuing year that progress towards remediation is not undertaken by Defendants. Such costs and risks arise both from damage caused by accumulated greenhouse gas emissions and from the required outlays on future remediation and adaptation efforts, which grow more expensive as the accumulation of greenhouse gases in the atmosphere increases. There are particularly consequential risks arising from the potentially catastrophic impacts of climate change, which increase each year that Defendants defer action on greenhouse-gas mitigation efforts.

c. Moving the U.S. economy away from fossil fuels is both feasible and beneficial, especially over the next 30 years (as technological and scientific evidence discussed below makes clear). Defendants could facilitate this transition with standard economic tools for dealing with externalities, for example a tax or levy on carbon (a price on the externality) and the elimination of subsidies on fossil-fuel production. Relatedly, decisions concerning the transition off of fossil fuels can be reached more systematically and efficiently by revising current government discounting practices, the methodology by which future costs are compared to present costs. Current and historical government decision making practices based on incorrect discount rates lead to inefficient and inequitable outcomes that impose undue burdens on Youth Plaintiffs and future generations. Basing decisions (policies, programs, and actions) on appropriate discount rates would help minimize the burdens that Defendants' current policies place on Youth Plaintiffs and future generations. That is to say, if Defendants' discounting policies and practices more accurately reflected the expected changes in relative prices over time (and their distribution, implicitly putting a lower discount rate on climate change benefits), the basis for Defendants' policy-making decisions would more closely align with economic principles and yield more efficient outcomes.

d. Based on this reasoning, I conclude that Defendants can and should take meaningful actions to reduce GHG emissions from fossil fuels and mitigate climate change impacts now rather than defer action to some future date. Acting now will yield benefits for both Defendants and Youth Plaintiffs and reduce harm to Youth Plaintiffs, and the costs of mitigating climate change now are manageable. Defendants could make meaningful progress on climate change mitigation by acting today in accordance with the best available science. Moreover, Defendants meeting their constitutional and public trust obligations to redress climate change would improve societal well-being by any reasonable economic standard. In fact, some of the actions that Defendants could take to meet these obligations would actually have a negative cost. That is to say, in the long run, the net present value of benefits to society would exceed the net present value of costs that society would have to incur.[4] This is referred to as Kaldor–Hicks efficiency in standard economic analysis, typically a hallmark of sound policymaking, from an economic perspective, whereby the net benefits of a policy change outweigh the net costs of such policy change. Thus, if Defendants were to make such changes as are argued for by other of Plaintiffs' experts, the net societal gain would more than outweigh the net societal loss. In contrast, Defendants' current policies of perpetuating the fossil fuel-based energy system impose unacceptably high costs and risks on the Youth Plaintiffs specifically and Affected Children more generally, and will continue to do so, well out of portion to the amounts that Defendants save currently by avoiding taking the appropriate actions.

20. The body of my report sets out the factual and analytical bases for my conclusions and opinions. The balance of my report proceeds as follows: Section III summarizes the scientific evidence on increasing greenhouse gases affecting global temperatures and why the time to act is now; Section IV discusses the costs that Youth Plaintiffs will face if Defendants continue to promote and permit a fossil-fuel-based energy system and no

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[4] This is not to say that each party is better off (which would be a Pareto improvement); but those parties who are better off by the policy change (e.g.., non-polluters) are made better off by more than the parties made worse off by the policy change (e.g.., polluters) are made worse off.

actions (or insufficient actions) are taken to wean society off fossil fuels; Section V analyzes how the transition away from fossil fuels is feasible and can be facilitated with standard economic tools; and, finally, Section VI concludes.

III. BACKGROUND ON THE RELATIONSHIP BETWEEN ATMOSPHERIC CONCENTRATIONS OF GREENHOUSE GASES AND CLIMATE CHANGE

21. The climate change young people are experiencing today is caused by the historic emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs), primarily from burning fossil fuels and other anthropogenic activities, including deforestation and agricultural practices.[5] It is scientifically established that human activities produce GHG emissions, which accumulate in the atmosphere and the oceans, resulting in warming of Earth's surface and the oceans[6], acidification of the oceans,[7] increased variability of climate, with a higher incidence of extreme weather events, and other changes in the climate.

22. Dangerous impacts are already occurring from the current level of global warming of around 1°C above preindustrial temperatures. Climate scientists have established through the paleo record that warming of 1.5°C or 2°C above pre-industrial levels would be well outside the Holocene range of global temperatures within which humans have lived and

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5 See, for example, Intergovernmental Panel on Climate Change, "Climate Change 2014: Synthesis Report Summary for Policymakers," pp. 4-5. Other Greenhouse Gases, like Methane, also trap heat within the earth. They differ in key technical properties, like the rate of dissipation. Throughout this report, I use the terms GHG and CO_2 emissions interchangeably.

There is a popular but misguided debate among so-called climate "skeptics" about the extent to which the observed increase in temperature is a result of the emissions of CO_2 and other GHGs. The scientific literature is clear (and has been clear for a long time): the increase in atmospheric concentration of GHGs predictably increases the Earth's temperature in the manner observed. This has been most recently reaffirmed by "Climate Science Special Report: Fourth National Climate Assessment, Volume I" U.S. Global Change Research Program, November 2017, pp. 96-97 https://science2017.globalchange.gov/downloads/CSSR2017_FullReport.pdf. (Hereinafter USGCRP Climate Science Special Report).

But even if there were other factors contributing to climate change, the analysis here is unchanged: Defendants could, with mild costs, take actions now that would avoid imposing the undue and excessive burdens and risks imposed on the Youth Plaintiffs in this case.

6 USGCRP Climate Science Special Report, p. 364.

7 USGCRP Climate Science Special Report, pp. 371-372.

societies developed.[8] Moreover, leading experts believe that there is already more than enough excess heat in the climate system to do severe damage and that 2°C of warming would have very significant adverse effects, including resulting in multi-meter sea level rise.[9] NOAA projects up to 0.63 m (2.1 feet) of sea level rise by 2050, 1.2 m (3.9 feet) by 2070, 2.5 m (8.2 feet) by 2100, 5.5 m (18 feet) by 2150, and 9.7 m (31.8 feet) by 2200.[10] A 2-3 foot sea level rise would inundate and render uninhabitable large portions of the world's barrier islands and deltas and place major pressures on the infrastructure of low-lying coastal zones like South Florida, and 3 feet of seal level rise would "permanently inundate 2 million American's homes and communities."[11] Sea level rise of this magnitude would impose irreversible harm and an immense financial burden on young people in coastal areas, along with significant indirect costs on young people elsewhere.

23. Experts have identified a number of known "feedback loops" in the climate system. These feedback loops cause warming to catalyze still further warming. For example, warmer arctic temperatures result in melting permafrost that releases methane, a GHG that further warms the planet. These feedbacks, in conjunction with the fact that CO_2 persists in the atmosphere for centuries, mean that the longer we delay action, the greater the risk that warming will trigger tipping points in the climate system and become irreversible, or reversible only at much increased cost. Given the self-reinforcing nature

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8 J. Hansen et al., "Assessing ''Dangerous Climate Change': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature," *PLOS One*, 8:12, e81648, 2013, p. 9.

9 J. Hansen, et al., "Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2C global warming is highly dangerous," *Atmospheric Chemistry and Physics Discussions*, 15, 20059-179, 2015, http://faculty.sites.uci.edu/erignot/files/2017/06/Ice-melt-sea-level-rise-and-superstorms-evidence-from-paleoclimate-data-climate-modeling-and-modern-observations-that-2C-global-warming-is-highly-dangerous.pdf.

10 "Global and regional sea level rise scenarios for the United States," NOAA Technical Report NOS CO-OPS 083, January 2017, p. 23, https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf.

11 H. Wanless, "Declaration of Dr. Harold R. Wanless in Support of Answer of Real Parties in Interest to Petition for Writ of Mandamus", *in United States of America et al. v. United States District Court for the District of Oregon et al.*, Case No. 17-71692, Doc. No. 14-3, paras. 31-32, *citing* "Global and regional sea level rise scenarios for the United States," NOAA Technical Report NOS CO-OPS 083, January 2017.

of climate change, prompt action is needed to both minimize future emissions and reduce the effects of historic emissions.

24. Experts have observed an increased incidence of climate-related extreme weather events, including increased frequency and intensity of extreme heat and heavy precipitation events and more severe droughts and associated heatwaves. Experts have also observed an increased incidence of large forest fires; and reduced snowpack affecting water resources in the western U.S. The most recent National Climate Assessment projects these climate impacts will continue to worsen in the future as global temperatures increase.[12]

25. Although the scale of the problems and risks that we face are immense, it is possible to reduce these risks by acting now to avoid irreversible harm to essential natural systems with its catastrophic consequences such as sea level rise, increased ocean temperatures, ocean acidification, heat waves, increased drought, and the associated impacts on water quality and availability, human health, and agriculture. Such impacts would harm our economy directly and introduce much increased risk in the form of variability in and uncertainty around climate outcomes.

26. Dr. Hansen and other experts in this case have provided a prescription for an emissions reduction and carbon sequestration pathway back to CO_2 levels below 350 ppm by 2100, which they say would substantially lessen the risk of catastrophic sea level rise and other climate harms.[13] Returning to temperatures and atmospheric CO_2 levels that avoid dangerous anthropogenic climate change has a limited window (because of tipping points in the climate system), which is still open but is closing rapidly. Defendants must take action now to reduce these risks.

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12 USGCRP Climate Science Special Report, pp. 19-22.

13 James Hansen et al., "Assessing ''Dangerous Climate Change': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature," *PLOS One*, 8:12, e81648, 2013.

IV. DEFENDANTS' ACTIONS THAT PERPETUATE A FOSSIL FUEL ENERGY SYSTEM AND INSUFFICIENT ACTION ON CLIMATE CHANGE ARE IMPOSING AND WILL CONTINUE TO IMPOSE ENORMOUS COSTS ON YOUTH PLAINTIFFS

27. The current national energy system, in which approximately 80 percent of energy comes from fossil fuels, is a direct result of decisions and actions taken by Defendants.[14] Defendants control and dictate the U.S. national energy policy in a myriad of ways. For example, they provide billions of dollars annually in subsidies to the fossil fuel industry;[15] control the fuel economy of cars and trucks through the Corporate Average Fuel Economy ("CAFE") standard; set efficiency standards for appliances; permit the extraction, transportation, import, export, and combustion of fossil fuels; and provide funding for research and development.[16] The fact that the U.S. national energy system is so predominately fossil fuel-based is not an inevitable consequence of history. With the oil crises of the 1970s, recognition of the risks of dependence on oil was developed (though these risks were markedly different from those with which we are concerned today). Even then, it was clear that there were viable alternatives, and with the appropriate allocation of further resources to R&D, it is likely that these alternatives would have been even more competitive. Thus, the current level of dependence of our energy system on fossil fuels is a result of intentional actions taken by Defendants over many years (including subsidization of fossil fuels and *inactions* in the form of not providing adequate support for alternatives).[17] Cumulatively, these actions promote the use of fossil fuels, contribute to dangerous levels of CO_2 emissions, and cause climate change. The economic impacts of these actions are deleterious to Youth Plaintiffs and the nation as a whole. In other words, Defendants' actions promoting a fossil fuel based

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[14] U.S. Energy Information Administration, Table 1.3 Primary Energy Consumption by Source, August 2017 Monthly Energy Review, https://www.eia.gov/totalenergy/data/browser/xls.php?tbl=T01.03&freq=m.

[15] See, Section V, below.

[16] "Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2013", U.S. Energy Information Administration, March 2015, https://www.eia.gov/analysis/requests/subsidy/pdf/subsidy.pdf.

[17] I would note that inactions in this sense are affirmative decisions by Defendants not to act.

energy system are serving to undermine the legitimate government interests of national security and economic prosperity that they purport to advance.[18]

28. When conducting an economic analysis of the effects of climate change and appropriate responses thereto, Defendants must take into account a number of salient aspects of climate change. I have already noted some of these aspects: not just global warming in the sense of on-average increases in temperature, but also an increase in extreme (and damaging) weather events, rising sea levels, the public health consequences, and many other direct and indirect impacts of climate change. Still another aspect of climate change that is crucial in framing an appropriate response are the long lag times inherent in the climate system, implying that the full climate impact of any given accumulation of GHGs may not be apparent for many years.[19] Moreover, critical to the effects (as already noted) is the increase in concentration of GHGs. The fact that GHGs dissipate very slowly from the atmosphere (particularly in the case of CO_2[20]) and that the costs of taking

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[18] Daniel R. Coats, Director of National Intelligence, "Statement for the Record: Worldwide Threat Assessment of the US Intelligence Community," *Office of the Director of National Intelligence*, February 13, 2018, https://www.intelligence.senate.gov/sites/default/files/documents/os-dcoats-021318.PDF (at page 16: "The impacts of the long-term trends toward a warming climate, more air pollution, biodiversity loss, and water scarcity are likely to fuel economic and social discontent—and possibly upheaval….").

[19] Because of these lags, we have not yet seen the full rise in temperature that will occur as a result of the CO_2 that has already been emitted. As noted above, the Earth's average surface temperature has already risen by approximately 1°C since the Industrial Revolution. The concentration of CO_2 in the atmosphere is increasing at the rate of 2-3 ppm per year. Scientists tell us that even if CO_2 were stabilized at current levels, there would be at least another 0.5°C "in the pipeline." The delayed response is known as climate lag. The reason the planet takes several decades to respond to increased CO_2 is the thermal inertia of the oceans. Consider a saucepan of water placed on a gas stove. Although the flame has a temperature measured in hundreds of degrees C, the water takes a few minutes to reach boiling point. This simple analogy explains climate lag. The mass of the oceans is around 500 times that of the atmosphere. The time that it takes to warm up is measured in decades. For example, a paper by Dr. Hansen (and others) estimates the time required for 60 percent of global warming to take place in response to increased emissions to be in the range of 25 to 50 years. See, Hansen, J.E. et al., "Earth's Energy Imbalance: Confirmation and Implications," *Sciencexpress*, April 28, 2004, http://science.sciencemag.org/content/early/2005/04/28/science.1110252.

[20] Accumulations of CO_2 are particularly problematic because they dissipate so slowly. See, e.g., "Carbon is forever," *Nature Reports Climate Change,* November 20, 2008. This article discusses results from Dr. Hansen's research, stating: "Several long-term climate models, though their details differ, all agree that anthropogenic CO_2 takes an enormously long time to dissipate. If all recoverable fossil fuels were burnt up using today's technologies, after 1,000 years the air would still hold around

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CO_2 out of the atmosphere through non-biological carbon capture and storage are very high[21] means that the consequences of GHG emissions should be viewed as effectively irreversible. Accordingly, if Defendants do not take serious action to mitigate climate change now, Youth Plaintiffs and Affected Children will largely shoulder the costs caused by Defendants' actions that contribute to the further accumulation of GHGs and Defendants' failure to act to redress the harm. We can expect these burdens to manifest themselves in at least four ways.

29. ***First***, despite their relative lack of economic power in society today, Youth Plaintiffs themselves will suffer the disproportionate, increased financial burdens of climate change as the impacts of climate change propagate throughout the economy. For example, rising sea levels will lead to massive reductions in property value (indeed, the value of land that is underwater will fall to zero). Some Youth Plaintiffs, such as Levi D., and Affected Children will (with high probability) be deprived of the use of submerged lands, and many of them will almost surely experience large capital losses, as markets eventually fully reflect the realities of climate change. In addition, Youth Plaintiffs and Affected Children will, as future taxpayers, help bear the enormous cost of relocating the people and infrastructure that are now on this land to higher ground. Youth Plaintiffs and Affected Children will also bear the cost of instituting temporary stopgap measures, such as dikes to hold back rising sea levels, and some of them will have to bear directly themselves relocation costs.

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a third to a half of the CO_2 emissions. 'For practical purposes, 500 to 1000 years is 'forever,'' as Hansen and colleagues put it. In this time, civilizations can rise and fall, and the Greenland and West Antarctic ice sheets could melt substantially, raising sea levels enough to transform the face of the planet."

[21] See, for example, House, K.Z., et al., "Economic and energetic analysis of capturing CO_2 from ambient air," *Proceedings of the National Academy of Sciences,* 108(51) (December 2011): 20428-20433, http://www.pnas.org/content/108/51/20428.full.pdf. The authors concluded: "Our empirical analysis of energetic and capital costs of existing, mature, gas separation systems indicates that air capture processes will be significantly more expensive than mitigation technologies aimed at decarbonizing the electricity sector. Unless a technological breakthrough that departs from humankind's accumulated experience with dilute gas separation can be shown to "break" the Sherwood plot and the second-law efficiency plot—and the burden of proof for such a process will lie with the inventor—direct air capture is unlikely to be cost competitive with CO_2 capture at power plants and other large point sources."

30. ***Second***, Youth Plaintiffs and Affected Children will face increased burdens as taxpayers because, as Defendants and climate scientists project, climate change will increase future losses related to climate variability, sometimes of a catastrophic nature.[22] In previous cases of catastrophic loss, society as a whole has borne much of the cost in the form of disaster relief payments from the public sector.[23] Recent examples of catastrophes in which a large proportion of the losses were borne by the public sector include Hurricane Katrina, Hurricane Sandy, Hurricane Harvey, Hurricane Irma, and Hurricane Maria. Each of these disasters has (or will) cost the public sector billions of dollars in disaster relief. For instance, Hurricane Sandy cost the U.S. government over $50 billion, which is three times larger than the $18.7 billion of insured losses from that disaster, and over 70

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[22] "The Impact of Climate Change on Natural Disasters," NASA, https://earthobservatory.nasa.gov/Features/RisingCost/rising_cost5.php. "Global Warming and Hurricanes," National Oceanic and Atmospheric Association, https://www.gfdl.noaa.gov/global-warming-and-hurricanes/. "Climate Change Indicators: Weather and Climate," EPA, https://www.epa.gov/climate-indicators/weather-climate. See also, K. Trenberth et al., "Attribution of climate extreme events," *Nature Climate Change* 5 (2015): 725-730.

[23] "Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget", Congressional Budget Office (CBO), June 2016, https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/reports/51518-hurricane-damage.pdf.

Public sector relief is needed in these cases because private risk-pooling solutions, such as property and casualty insurers, do not and cannot cover even a majority of the realized losses. This is true for three primary reasons. *First*, a significant portion of the population is uninsured or underinsured for certain types of losses such as the risk of flood, especially in areas that have not been historically prone to flooding. *Second*, public property may not be insured at all. *Third*, property and casualty insurers are sometimes insufficiently capitalized to cover the enormous losses that such events can potentially cause, and their insolvency forces policyholders to turn to the government for assistance.

This point is illustrated by Hurricane Harvey in 2017, where some estimates of the costs run to nearly $200 billion, which represents about 1 percent of gross national product. See, e.g., Doyle Rice, "Harvey to be costliest natural disaster in U.S. history, estimated cost of $190 billion," *USA Today*, August 31, 2017, https://www.usatoday.com/story/weather/2017/08/30/harvey-costliest-natural-disaster-u-s-history-estimated-cost-160-billion/615708001/ and Reuters, "Hurricane Harvey Damages Could Cost up to $180 Billion," *Fortune*, September 3, 2017, http://fortune.com/2017/09/03/hurricane-harvey-damages-cost/. The Treasury Secretary went so far as to speculate that the Federal government's debt limit would have to be raised to free up spending for disaster recovery, and the Governor of Texas estimated that such relief could require $180 billion. *Id.*

Estimates for Hurricane Maria have been on the order of $100 billion. See, Jill Disis, "Hurricane Maria could be a $95 billion storm for Puerto Rico," *CNN*, September 28, 2017, http://money.cnn.com/2017/09/28/news/economy/puerto-rico-hurricane-maria-damage-estimate/index.html.

percent of the total economic damage of the disaster as estimated by the CBO.[24] Hurricane Katrina cost the U.S. government over $110 billion, 75 percent of the total economic damages of the disaster.[25] With increased catastrophic losses due to climate change, we can expect that the U.S. government's role as a safety net will expand.[26] As this trend continues, taxpayers of the future, including Youth Plaintiffs, will have to make whole the losses of property owners. The continuation, let alone the expansion, of the public sector's role as a safety net will be enormously costly, impose an increased burden and economic disadvantage on Youth Plaintiffs and Affected Children compared to older generations, and result in fewer government resources to be spent on public services.[27]

31. The National Centers for Environmental Information tracks the impact of weather events on the United States. As they report, from 1980 to 2017 the U.S. has experienced "219 weather and climate disasters since 1980 where overall damages/costs reached or exceeded $1 billion (including CPI adjustment to 2017). **The total cost of these 219 events exceeds $1.5 trillion.**"[28] (Emphasis in original.) In describing the impact on the U.S. in 2017 (the last full year):[29]

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24 "Catastrophes: U.S.," Insurance Information Institute, http://www.iii.org/fact-statistic/catastrophes-us. "Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget", Congressional Budget Office (CBO), June 2016, https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/reports/51518-hurricane-damage.pdf.

25 "Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget," Congressional Budget Office (CBO), p. 17, https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/reports/51518-hurricane-damage.pdf.

26 "Underinsurance of Property Risks: Closing the Gap," Swiss Re, No. 5/2015, http://institute.swissre.com/research/overview/sigma/5_2015.html.

27 The CBO estimates that, by 2075, hurricane losses alone will total 0.22 percent of GDP, or $39 billion in 2016 dollars, an increase of 40 percent from today's annual levels, and over half of that loss will be borne by the U.S. government. "Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget," Congressional Budget Office, https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/reports/51518-hurricane-damage.pdf.

28 "Billion-Dollar Weather and Climate Disasters: Overview," National Centers for Environmental Information, 2018, https://www.ncdc.noaa.gov/billions/.

29 *Id.*

> In 2017, there were 16 weather and climate disaster events with losses exceeding $1 billion each across the United States. These events included 1 drought event, 2 flooding events, 1 freeze event, 8 severe storm events, 3 tropical cyclone events, and 1 wildfire event. Overall, these events resulted in the deaths of 362 people and had significant economic effects on the areas impacted.

32. As the above makes clear, it is not just hurricanes that can cause such costly events. The 2017 wildfire season in California was particularly harsh. Insurance claims at the end of 2017 were approximately $9.4 billion (with many properties being underinsured or not insured, the total damage is higher),[30] and estimates of the total impact on economic activity were $180 billion (including damages, closures, costs to fight fires, lost sales, etc.).[31] In 2016, Canada had a similar experience in Fort McMurray, Alberta; insurance payments were the costliest in Canadian history at CAD 3.58 billion,[32] and this covered only 70 percent of the total economic loss.[33] Particularly insidious with forest fires is that they also lead to massive injections of CO_2 into the atmosphere. As the Climate Science Special Report (a compilation by the U.S. Global Change Research Program, spanning multiple government agencies) noted about the Alberta wild fires specifically: "They can also radically increase emissions of greenhouse gases, as demonstrated by the amount of carbon dioxide produced by the Fort McMurray fires of May 2016—more than 10% of Canada's annual emissions."[34] The federal government expends significant financial

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[30] W. Richter, "We may never be able to know the true cost of California's massive wildfires," *Business Insider*, December 7, 2017, http://www.businessinsider.com/santa-rosa-california-fires-cost-damage-2017-12.

[31] "AccuWeather predicts 2017 California wildfire season cost to rise to $180 billion," *AccuWeather*, December 8, 2017, https://www.accuweather.com/en/weather-news/accuweather-predicts-2017-california-wildfire-season-cost-to-rise-to-180-billion/70003495.

[32] "Northern Alberta Wildfire Costliest Insured Natural Disaster in Canadian History – Estimate of insured losses: $3.58 billion," Insurance Bureau of Canada, July 7, 2016, http://www.ibc.ca/ab/resources/media-centre/media-releases/northern-alberta-wildfire-costliest-insured-natural-disaster-in-canadian-history.

[33] W. Koblensky, "Fort McMurray in top 10 worst insured losses globally," Insurance Business Canada, March 29, 2017, http://www.insurancebusinessmag.com/ca/news/environmental/fort-mcmurray-in-top-10-worst-insured-losses-globally-63960.aspx.

[34] USGCRP Climate Science Special Report, p. 415.

resources each year on both fire suppression efforts and in the aftermath of wildfires, and while costs do vary from year to year, in general, they are rising.[35]

33. Other potential examples include agricultural losses. Whether or not insurance reimburses farmers for their crops, there can be food shortages that lead to higher food prices (that will be borne by consumers, that is, Youth Plaintiffs and Affected Children). There is a further risk that as our climate and land use pattern changes, disease vectors may also move (e.g., diseases formerly only in tropical climates move northward).[36] This could lead to material increases in public health costs in terms of vaccinations and treatments, at least some portion of which will be borne by future taxpayers, i.e., Youth Plaintiffs and Affected Children. Moreover, the Youth Plaintiffs and Affected Children will be at risk of experiencing directly one or more of these increased health hazards, only a portion of the costs of which will be picked up by insurance or public assistance. There is a risk too that the increased health costs will be reflected in increased insurance premiums, affecting all those relying on private insurance, including some or all of the Youth Plaintiffs and Affected Children.

34. All of these factors will also lead to increasing inequality, as those with financial means are more able to privately bear the costs of these disasters, while those without financial means will not. Those with means will also be able to relocate, perhaps avoiding (for themselves) the burdens of rising sea levels. This will impose a greater burden on those less able to pay for the direct, local consequences of climate change. Such increasing inequality is bad not only for those made worse off, but also for society as a whole, as a more unequal society is one with poorer economic performance.[37] This will impose

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[35] See, e.g., K. Hoover & B. Lindsay, "Wildfire Suppression Spending: Background, Issues, and Legislation in the 115th Congress," Congressional Research Service, October 5, 2017, https://fas.org/sgp/crs/misc/R44966.pdf.

[36] See, e.g., G. Mercer, "The Link Between Zika and Climate Change," *The Atlantic*, February 24, 2016, https://www.theatlantic.com/health/archive/2016/02/zika-and-climate-change/470643/.

[37] See, e.g., OECD, "Inequality hurts economic growth, finds OECD research," September 12, 2014, http://www.oecd.org/newsroom/inequality-hurts-economic-growth.htm and Prakash Loungani and Jonathan D. Ostry, "The IMF's Work on Inequality: Bridging Research and Reality," IMF, February 22, 2017, https://blogs.imf.org/2017/02/22/the-imfs-work-on-inequality-bridging-research-and-reality/ ("Another important conclusion of IMF research: rising inequality poses risks to durable

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further costs on the Youth Plaintiffs and Affected Children as they have to adapt to a structurally weaker economy due to increasing inequality (as elaborated on below, inequality is also exacerbated by Defendants' subsidy system that takes from taxpayers and gives to fossil-fuel corporations).

35. ***Third,*** Youth Plaintiffs will face increased burdens because the more time that passes, the more expensive it becomes to address climate change.[38] It is highly likely that, as the consequences and magnitude of climate change become manifest, there will finally be a global consensus for a globally equitable and efficient response.[39] At that juncture, the only way to prevent the accumulation of greenhouse gases beyond a tolerable level will be "negative emissions," i.e. taking carbon out of the atmosphere, effectively attempting to undo the damage that is currently being done.[40] That will be enormously expensive relative to what it would have cost to begin curtailing emissions today.[41] Further, there is no guarantee that Youth Plaintiffs will be able to timely and effectively repair this

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economic growth. This puts addressing inequality squarely within the IMF's mandate to help countries improve economic performance.").

[38] See, e.g., "Climate change in the United States: Benefits of Global Action", EPA. Beccherle, Julien and Tirole, Jean, "Regional Initiatives and the Cost of Delaying Binding Climate Change Agreements", *Journal of Public Economics* 95 (December 2011): 1339-1348. Jakob, Michael and Tavoni, Massimo, "Time to act now? Assessing the costs of delaying climate measures and benefits of early action", *Climate Change* 114 (2012): 79-99.

[39] See, for example, Climate change in the United States: Benefits of Global Action, EPA, https://www.epa.gov/sites/production/files/2015-06/documents/cirareport.pdf.

[40] See, for example, "The cost of delaying action to stem climate change," Executive Office of the President of the United States, July 2014, p. 13, https://obamawhitehouse.archives.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf.

[41] Even as these costly actions to undo the damage are undertaken, the effects of failing to act now will likely be felt, in ways described earlier in this report. Each and every one of the Youth Plaintiffs will face a risk of being personally affected, e.g., by increased taxes, increased direct losses, and increased exposure to health risks and to climate variability itself.

A recent estimate pegged the costs of CO_2 extraction to be on the order of $8 to $18.5 trillion, or over $100 billion per year over 80 years, to return to a 350 ppm target by 2100. These costs are much higher with continued high emissions (i.e., if we do not cease fossil fuel use and rely only on carbon capture and storage), being on the order of $100 *trillion* or more. See, J. Hansen et al., "Young People's Burden: Requirement of Negative CO_2 Emissions," *Earth System Dynamics*, vol. 8, 2017, pp. 577-616, at 591-592.

damage. In other words, the actions of Defendants in promoting and perpetuating a fossil fuel-based energy system impose a disproportionately higher financial burden and economic disadvantage on Youth Plaintiffs and Affected Children, undermining their economic security and depriving them of the stronger economy that they would have had in the absence of unmitigated climate change.

36. ***Fourth,*** in the absence of mitigation efforts, there is a significant risk of catastrophic impacts of climate change; indeed, there is overwhelming evidence that such catastrophic impacts are likely to result. Defendants' failure to invest in climate change mitigation and thereby insure against that outcome imposes an enormous degree of risk on Youth Plaintiffs, not experienced by older generations. Events such as the rapid melting of ice sheets and consequent increases in global sea levels or temperature increases on the higher end of the range of scientific forecasts have the potential to entail severe, perhaps even irreparable, consequences.[42] To confront properly the possibility of climate catastrophes, Defendants must take prudent steps now to reduce the chance of the most severe consequences of climate change. The longer Defendants postpone such action, the greater will be the atmospheric concentration of GHGs and the risk (due to the self-reinforcing and path-dependent[43] nature of climate systems and long lags between actions and results, as discussed above). Just as businesses and individuals guard against severe financial risks by purchasing various forms of insurance, Defendants can take actions now that reduce the chances of triggering the most severe climate events. There is no third party from which Defendants could purchase insurance to protect Youth Plaintiffs from the damages that are consequent to Defendants' actions. The only alternative for Defendants is to take actions without delay to reduce the atmospheric concentration of CO_2 in order to restore Earth's energy balance and avert catastrophic and irreversible

42 See, Section III, above.

43 By path dependence, I mean that prior actions affect the future trajectory of the economy in ways that are not irreversible, or reversible only at high costs. Accordingly, what is a prudent strategy today depends on decisions made yesterday (and many years ago). Put differently, prior decisions are not something that we can now just walk away from; those prior decisions directly affect the world we live in today and affect the analysis of what is a prudent strategy going forward.

climate change impacts.[44] Unlike conventional insurance policies, climate and energy policy that serves the purpose of climate insurance also results in cleaner air, improved energy security, and other benefits, many of which are difficult to monetize, like biological diversity or preserving culturally important places, but are nonetheless significant.

37. The benefits of undertaking such actions are disproportionate to the costs, even without taking account of the huge benefits that arise from the reduction of risk itself. This has been documented, for example, in the High-Level Commission on Carbon Prices.[45] Due to feedback loops, the magnitude of climate change may change much more than the proportionate increase in atmospheric concentrations of GHGs. Likewise, the increases in atmospheric concentrations of GHGs may increase disproportionately relative to emissions,[46] and the cost of damage wrought by climate change can increase much faster still.[47] More is being learned about the behavior of the climate system, including the potential timing and likelihood of these worst-case scenarios. However, the paleo-climate record gives scientists at least one good indication of the consequences of different levels of atmospheric CO_2. The last time in the geologic record that CO_2 levels were over 400 ppm, the seas were 70-90 feet higher than sea level today.[48] The experience of the last

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[44] J. Hansen, "Exhibit A: Declaration of Dr. James E. Hansen in Support of Plaintiffs' Complaint for Declaratory and Injunctive Relief," in *Juliana et al. v. United States et al.*, Case No. 6:15-cv-01517-TC, Doc. No. 7-1., 2015, paras. 39, 67, 85.

[45] The Commission showed that even a modest tax on carbon combined with the elimination of subsidies and certain other regulatory measures and modest public investments would be able to prevent a rise of temperature beyond the 1.5°C to 2°C.

[46] See, for example, "The study of Earth as an integrated system," NASA, https://climate.nasa.gov/nasa_science/science/ and National Research Council of the National Academies, "Climate Change: Evidence, Impacts, and Choices," *The National Academies of Sciences, Engineering, and Medicine*, 2012, http://nas-sites.org/americasclimatechoices/files/2012/06/19014_cvtx_R1.pdf.

[47] This is discussed in the Stern Review. See, for example, Figure 6.6 showing the exponential increase in reduced GDP per capita as global mean temperature increases. Nicholas Stern, "Stern Review: The Economics of Climate Change", p. 159, http://unionsforenergydemocracy.org/wp-content/uploads/2015/08/sternreview_report_complete.pdf.

[48] H. Wanless, "Declaration of Dr. Harold R. Wanless in Support of Answer of Real Parties in Interest to Petition for Writ of Mandamus", *in United States of America et al. v. United States District Court for the District of Oregon et al.*, Case No. 17-71692, Doc. No. 14-3, para. 52.

quarter century is that there have been many surprises of underestimating adverse climate impacts (e.g., early estimates of sea level rise had not taken into account the effect of the melting of the arctic icecap or the release of methane gases from the tundra).[49]

38. Fair treatment of Youth Plaintiffs by Defendants requires taking due account of some of the worst, but still plausibly possible, cases. In such cases, national income will be lower because of the adverse effects of climate change,[50] imposing doubly an increased financial burden and economic disadvantage on Youth Plaintiffs and Affected Children: they will face the costs of remediation and adaptation with fewer resources with which to do so. Even if national incomes continue to rise in real terms, the costs of taking remedial climate action are an ever-increasing burden on Youth Plaintiffs and Affected Children as well. Moreover, as discussed in the climate science summary above, we are quickly approaching (or some argue we may have already passed) certain "tipping points" that will dramatically increase costs in a non-linear fashion.[51] Thus, it is not a practical solution to say Youth Plaintiffs and future generations may be more wealthy in the future (in fact, GDP may be lower in the future because of climate effects) and can bear the costs more efficiently than Defendants today (because those costs continue to increase disproportionately and have long-lasting adverse effects). The assumption of ever-increasing national income has significant implications for Defendants' cost-benefit

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49 See, for example, Schneider, Stephen H. and Root, Terry L. Ecological implications of climate change will include surprises, *Biodiversity and Conservation* 5 (1996): 1109-1119.

50 In one recent study, researchers found that temperature change due to unmitigated global warming will leave global GDP per capita 23 percent lower in 2100 than it would be without any warming. See Burke, M., Hsiang, S. M., & Miguel, E., (2015) "Global non-linear effect of temperature on economic production," *Nature*, 527 (7577): 235-239.

A per capita 23 percent lowering of GDP is the on-average result, which understates the full potential impact in two ways (much as the on-average temperature increases understate the increase in catastrophic events, as I discussed above). *First*, a 23 percent on-average result includes many states of the world where the average may be much worse. *Second*, a 23 percent on-average result will not affect all persons or all regions equally; those near the bottom of the income distribution that have no savings will suffer from lack of ability to consume, and almost surely these effects will be felt more in coastal regions, from which those near the bottom of the income distribution will lack the financial resources to relocate, further exacerbating their financial difficulties.

51 See also, "The study of Earth as an integrated system," NASA, https://climate.nasa.gov/nasa_science/science/.

analysis and development of discount rates and the social cost of carbon, as described in more detail in Section V.C, below.

39. Moreover, it will be necessary to devote a significant proportion of national income to dealing with the consequences of climate change; the standard term is that there will be high costs of adaptation.[52] Especially disturbing are the impacts on developing countries, many of which are in tropical zones, which will be particularly hard hit. In the U.S., Youth Plaintiffs will not be able to insulate themselves from the global repercussions. The costs of adaptation to climate change by developing countries are well beyond anything that those countries can afford (or will be able to afford in the future). Youth Plaintiffs may recognize that they have a moral responsibility to global citizens elsewhere in the world because of the actions of the U.S., including Defendants, and thus they will bear a burden because of the failure of Defendants to take appropriate actions.[53] However, even were they not to do so, the markedly lower incomes in developing countries will set off large migration pressures, which we are already seeing today.[54]

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52 According to the United Nations Environment (UNEP) report, the cost of adapting to climate change in developing countries could rise to between $280 and $500 billion per year by 2050. There will be a significant financing gap unless new and additional finance for adaptation is made available. See UNEP 2016. The Adaptation Finance Gap Report 2016. United Nations Environment Programme (UNEP), Nairobi, Kenya

53 Of course, Defendants do not control global climate emissions. The U.S. is the second-largest current emitter of CO_2 at 15 percent of global emissions (behind only China), and by far the largest historical emitter of CO_2 and GHGs. See, EPA, "Global Greenhouse Gas Emissions Data," *United States Environmental Protection Agency*, data as of 2014, https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data#Country and J. Gillis and N. Popovich, "The U.S. Is the Biggest Carbon Polluter in History. It Just Walked Away From the Paris Climate Deal," *The New York Times*, June 1, 2017, https://www.nytimes.com/interactive/2017/06/01/climate/us-biggest-carbon-polluter-in-history-will-it-walk-away-from-the-paris-climate-deal.html.

However, action by the world's largest historical contributor of GHGs and the world's largest economy (the U.S.) would help further the goals of the Paris agreement and other countries' efforts to reduce GHG emissions. Moreover, it could reduce the incentive for other countries to shirk their climate change efforts by attempting to gain a competitive edge by not addressing climate change (a race to the bottom, so to speak). In any event, however, the fact that other countries, particularly developing countries, may not take as strong as action as is needed is not justification for Defendants using out-dated economic models and analysis to foist high costs on Youth Plaintiffs and Affected Children more generally.

54 See, for example, Coral Davenport and Campbell Robertson, "Resettling the First American 'Climate Refugees,'" *The New York Times*, May 3, 2016, https://www.nytimes.com/2016/05/03/us/resettling-

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Managing this migration (including possibly putting up hard-and costly-to-enforce barriers to it) will impose large costs on Youth Plaintiffs, undermining their economic security.[55] Moreover, in a globally interconnected system, lower incomes abroad will adversely affect the demand for American goods and services, thereby reducing U.S. GDP from what it otherwise would be, with consequent risks for Youth Plaintiffs and Affected Children.

40. I understand that Defendants argue their policies were necessary for the economic and national security of the U.S.[56] Such arguments do not withstand economic scrutiny. Whatever benefits might have existed in the middle of the 20th century, it has been decades since such policies were rational. This has been recognized by leading security experts. For example, since at least 2007, members of the U.S. military have recognized that "serious consequences to our national security … are likely from unmitigated climate

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the-first-american-climate-refugees.html and Aryn Baker, "How Climate Change is Behind the Surge of Migrants to Europe," *Time*, September 7, 2015, http://time.com/4024210/climate-change-migrants/.

[55] As discussed in the Stern Review, some estimates suggested up to 200 million people may become permanently displaced by climate change by the middle of this century, noting that almost as many people leave their homes because of environmental disasters as flee political oppression. See, Nicholas Stern, "Stern Review: The Economics of Climate Change", p. 77, http://unionsforenergydemocracy.org/wp-content/uploads/2015/08/sternreview_report_complete.pdf. See also, K. Burrows & P. Kinney, "Exploring the Climate Change, Migration and Conflict Nexus," *International Journal of Environmental Research and Public Health* 13(4) (2016): 443, noting that the number of people displaced by climate change by 2050 is estimated to be between 50 million, on the low end, and 1 billion, on the high end.

[56] See, e.g., "Office of Fossil Energy FY 2019 Budget," U.S. Department of Energy, https://www.energy.gov/fe/about-us/our-budget ("The Office of Fossil Energy (FE) programs are focused on activities related to the reliable, efficient, affordable, and environmentally sound use of fossil fuels that are essential to our Nation's security and economic prosperity.").

See also, Jason Furman and Gene Sperling, "Reducing America's Dependence on Foreign Oil As a Strategy to Increase Economic Growth and Reduce Economic Vulnerability," Obama White House Archives, August 29, 2013, https://obamawhitehouse.archives.gov/blog/2013/08/29/reducing-america-s-dependence-foreign-oil-strategy-increase-economic-growth-and-redu ("...the President's focus on increasing America's energy independence is not just a critical national security strategy, it is also part of an economic plan to create jobs, expand growth and cut the trade deficit." The first element of President's Obama plan was "Increasing domestic production of oil.").

change."[57] In a report released in 2007, eleven retired military generals and admirals detailed the variety of threats to America's national and economic security that climate change poses:[58]

> In already-weakened states, extreme weather events, drought, flooding, sea level rise, retreating glaciers, and the rapid spread of life-threatening diseases will themselves have likely effects: increased migrations, further weakened and failed states, expanded ungoverned spaces, exacerbated underlying conditions that terrorist groups seek to exploit, and increased internal conflicts. In developed countries, these conditions threaten to disrupt economic trade and introduce new security challenges, such as increased spread of infectious disease and increased immigration. Overall, climate change has the potential to disrupt our way of life and force changes in how we keep ourselves safe and secure by adding a new hostile and stressing factor into the national and international security environment.

41. From an economic perspective, one of the key insights is that, just at the time when money is scarce (and our economy is weak) because of climate change, there will be greater need for funds. Thus, government will be less able to provide the requisite finance for key public services, depriving Youth Plaintiffs and Affected Children of the economic benefits enjoyed by older generations. This makes it even more compelling for Defendants to take all the precautionary measures today that they can.

42. As noted by the High-Level Commission on Carbon Prices (the "High-Level Commission"), which I co-chaired, the estimated economic costs of climate change in many of the standard models, and in particular Defendants' estimates of the social cost of carbon (under the Obama administration), are:[59]

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[57] "National Security and the Threat of Climate Change," The CNA Corporation, 2007, p. 44, https://www.cna.org/cna_files/pdf/national%20security%20and%20the%20threat%20of%20climate%20change.pdf.

[58] "National Security and the Threat of Climate Change," The CNA Corporation, 2007, pp. 44-45, https://www.cna.org/cna_files/pdf/national%20security%20and%20the%20threat%20of%20climate%20change.pdf.

[59] High-Level Commission on Carbon Prices, "Report of the High-Level Commission on Carbon Prices", 2017, Washington, DC: World Bank, Appendix A.

> …biased downward because they fail to consider many vitally important risks and costs associated with climate change—particularly the widespread biodiversity losses, long-term impacts on labor productivity and economic growth, impacts on the poorest and most vulnerable, rising political instability and the spread of violent conflicts, ocean acidification, large migration movements, as well as the possibility of extreme and irreversible changes.

43. Thus, it is prudent for Defendants to take precautionary actions, not based on the "average" estimate of what the damage might be, but rather based on estimates of realistically plausibly possible "worst cases." Because, as detailed below, Defendants could take actions at modest costs, and it would be reckless not to undertake those actions; it would be needlessly endangering the future prospects and the economic and personal security of Youth Plaintiffs and Affected Children.

V. TRANSITIONING THE U.S. ECONOMY OFF OF FOSSIL FUELS IS NOT ONLY FEASIBLE BUT WILL BENEFIT THE ECONOMY

A. TRANSITIONING OFF OF FOSSIL FUELS IS FEASIBLE

44. There is broad consensus among economists, and the High-Level Commission concluded, that limiting temperature increase to "well below 2°C" is achievable with reasonable and modest measures, and that the costs of those measures are far smaller than the costs of the damage that climate change could inflict.[60]

45. The High-Level Commission estimated that the costs of curtailing emissions to a level to achieve the goals set forth by the Paris Agreement ("well below 2°C") would be modest.[61] The High-Level Commission noted that the carbon tax, that they explained could induce the requisite change in emissions, could substitute for other more distortionary taxes. If governments made such a substitution, the aggregate cost of curtailing carbon emissions could even be less than zero, providing net benefits to the economy. Furthermore, at a time when so much discussion focuses on the Federal government's deficit spending (and our national debt), the elimination of billions of dollars of often-hidden subsidies to the fossil fuel industry would improve the country's fiscal situation and economic performance generally. As discussed below in Section V.B, the full amount of post-tax subsidies in the U.S. has been estimated at nearly $700 billion a year, more than half of the Federal government's forecasted deficit for the next fiscal year.[62] Eliminating all fossil fuel subsidies (implicit and explicit, many of which

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[60] High-Level Commission on Carbon Prices, "Report of the High-Level Commission on Carbon Prices", 2017, Washington, DC: World Bank, p. 1.

[61] When I use the term "costs" here, I refer to the net effect of undertaking such policy changes—that is, such costs can be negative (when the benefits outweigh the costs). As is standard in economic analysis, I analyze the *marginal* effects, that is, the marginal (i.e., additional as compared to the *status quo*) net outlays that will be required for effectuating a given policy choice. Because certain policy choices can have long-term benefits that outweigh long-term costs, negative costs are a distinct possibility.

[62] Coady et al., "How Large Are Global Energy Subsidies?", IMF Working Paper, Fiscal Affairs Department, 2015, paper and underlying data available at: https://www.imf.org/en/News/Articles/2015/09/28/04/53/sonew070215a.

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go to large corporations) could, therefore, both curtail fossil-fuel production, through forcing companies to bear more of the true costs of fossil-fuel production, and substantially reduce our national deficit in one fell swoop. Equity would also be improved with corporations paying more and individuals, such as the Youth Plaintiffs and Affected Children, benefiting.

46. There are many reasons to be optimistic that emissions could be curtailed further than previously thought. These benefits are a result of continued technological development in the renewables sector. Because of technological improvements, the costs of renewables and storage are decreasing. The price of solar panels has dropped by more than half in recent years (80 percent reduction from 2008 to 2016).[63] In 2016 alone, the average dollar capital expenditure per megawatt for solar photovoltaics and wind dropped by over 10 percent.[64] As these technologies continue to improve and the efficiency increases, while manufacturing costs drop, these technologies will more easily substitute for existing fossil fuel infrastructure.

47. Transitioning to a non-fossil-fuel-based economy will require additional investment in our energy sector. Such sectoral shifts in our economy are not uncommon. In fact, a hallmark of a well-functioning market economy is its ability to shift between sectors as

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See also a report published by the Overseas Development Institute and Oil Change International, which found that as of 2014, the U.S. government provides approximately $20 billion annually in producer side subsidies through various tax exceptions/deductions.

Doukas, Alex, "G20 subsidies to oil, gas and coal production: United States", Overseas Development Institute, 2015, https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9979.pdf).

With the recent tax cuts, the deficit is currently forecasted to be about $1 trillion in the next fiscal year. See, Associated Press in Washington, "US deficit to approach $1tn after Trump tax cuts and spending bill, CBO says," *The Guardian*, April 9, 2018, https://www.theguardian.com/us-news/2018/apr/09/us-deficit-trump-tax-cuts-trillion-cbo-projection.

63 See, e.g., Ryan Whitman, "We could be headed for a solar power renaissance as costs keep dropping," *ExtremeTech*, December 19, 2016, https://www.extremetech.com/extreme/241300-headed-solar-power-renaissance-costs-keep-dropping.

64 Frankfurt School-UNEP Centre/BNEF, "Global Trends in Renewable Energy Investment 2017," 2017, http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2017.pdf.

technology changes and demand fluctuates. For example, we have seen shifts from agriculture to manufacturing to services over the course of the twentieth century, and we saw a shift towards the financial sector (from less than 3 percent to over 8 percent of GDP) from the 1950s to its peak in 2006 (immediately before the financial crisis).[65] Our spending on our energy sector has also fluctuated, as the chart below shows energy expenditures as a percent of GDP from 1970 to 2015. While the high levels of spending in the early 1980s (over 10 percent) were during periods of economic turbulence with high inflation and an energy crisis, there have been other periods, such as the 2000s and the early 1970s where there was economic growth and high spending on our energy system. Moreover, our economy has endured sudden, unplanned disruptions in the past (again, for example, the financial crisis); moving our economy to one without fossil fuels would come with a slight cost, but would be an event we can plan for to minimize disruptions (and would bring net benefits in the form of risk reduction).

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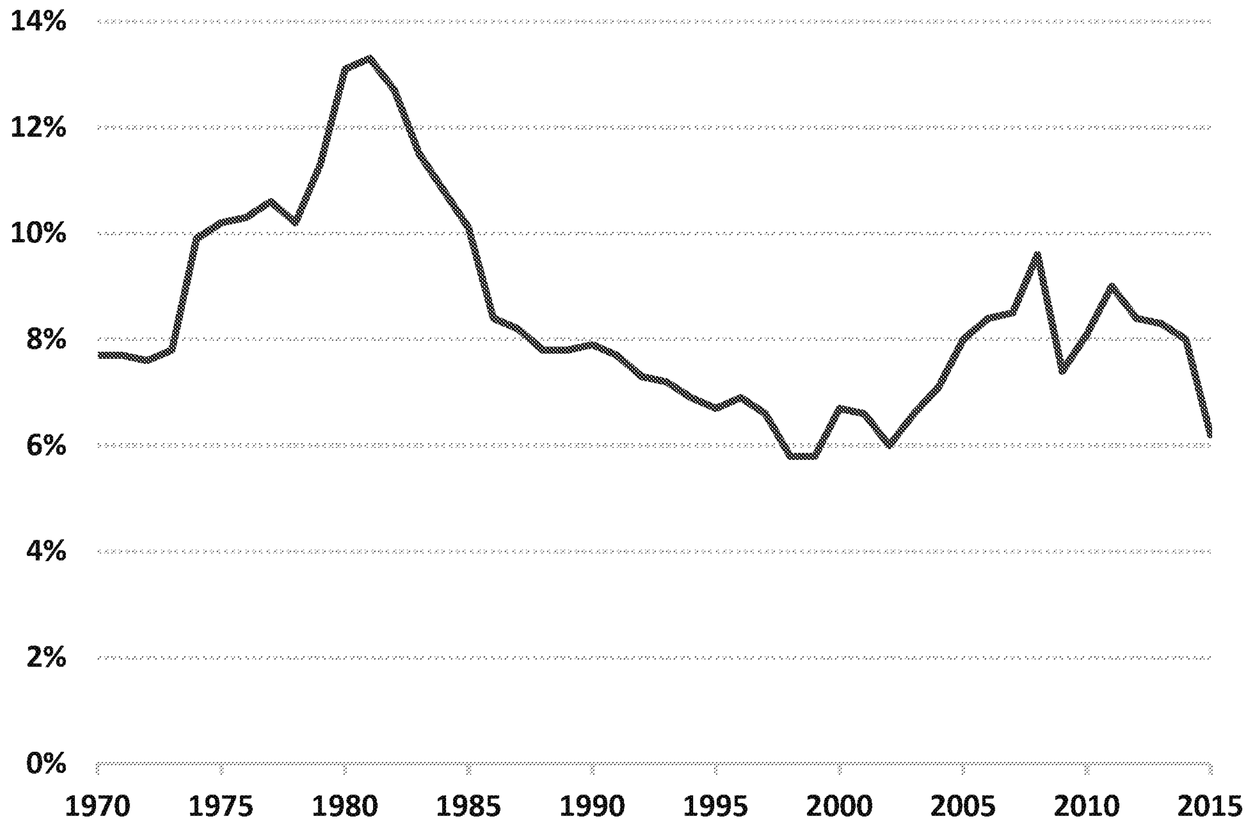
65 See, e.g., Robin Greenwood and David Scharfstein, "The Growth of Finance," *Journal of Economic Perspectives*, 27(2) (Spring 2013): 3-28.

Figure 1: Energy Expenditures as Share of GDP (Percent)



Source: U.S. Energy Information Administration, March 2018 Monthly Energy Review, Table 1.7 Primary Energy Consumption, Energy Expenditures, and Carbon Dioxide Emissions Indicators.

48. There are a number of important new "energy smart" technologies that can play a role in reducing dependence on energy, making our existing energy infrastructure more efficient.[66] Smart grids, for example, can turn on appliances when renewable electricity is plentiful—and ramp down electric loads when renewable power wanes. Advanced energy storage technologies are increasingly diverse and many, like ice energy storage, are simpler and can be more cost effective than chemical batteries. Electric vehicles can also be considered "energy smart" technology, as their charging and discharging of batteries can be flexible, creating great potential to improve the efficiency of our national energy infrastructure. These technologies reduce overall energy consumption, so that even without the introduction of less carbon intensive energy sources, they can reduce

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[66] Frankfurt School, UNEP Centre, "Global Trends In Renewable Energy Investment 2017," http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2017.pdf.

carbon emissions. Many energy efficiency technologies actually have a negative cost to implement, especially if one includes in the costs the implicit costs associated with GHG emissions (costs to society that are currently externalized).[67]

49. The major U.S. corporations that have committed themselves to dramatic emissions reductions—as well as state and local governments that have committed to emissions reductions—support the feasibility of a swift transition.[68] Creating predictability is of significant economic value in aggressively seeking to reduce emissions; i.e., it makes clear to players in the future economy that they can plan accordingly with very high confidence. In addition, this greater certainty facilitates the production of goods and services at lower costs. For instance, the Chief Executive Officers of Apple, BHP Billiton, BP, DuPont, General Mills, Google, Intel, Microsoft, National Grid, Novartis Corporation, Rio Tinto, Schneider Electric, Shell, Unilever, and Walmart all called on the President to stay the course with respect to United States' participation in the Paris Agreement.[69] So too, were the Defendants to adopt a high and reliable price of carbon, households and firms would know that it paid economically to adopt low- or zero-emission technologies and products.

50. In pursuing clean-energy technology, there is also the potential for increasing overall economic production and stimulating aggregate demand and economic growth. As I

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[67] See, e.g., European Commission, "The Macroeconomic and Other Benefits of Energy Efficiency", https://ec.europa.eu/energy/sites/ener/files/documents/final_report_v4_final.pdf.

[68] In 2017, for example, nine states making up the Regional Greenhouse Gas Initiative consortium agreed to a cap-and-trade program that seeks a 30 percent reduction in carbon pollution from energy plants by 2030. See, Colin Young, "9 states, including Mass., Agree to Accelerate Emission Reductions in Next Decade," *WBUR*, August 23, 2017, http://www.wbur.org/news/2017/08/23/9-states-including-mass-agree-to-extend-carbon-reduction-goals-to-2030.

Other state-driven strategies include California's January 2018 announcement to have 5 million zero-emission vehicles in use by 2030; Hawaii mandating that all of the state's electricity come from renewable sources by the mid-21st century; and Vermont's commitment to reduce emissions to 80-95 percent below 1990 levels by 2050. See, "U.S. Leads in Greenhouse Gas Reductions, but Some States are Falling Behind," Environmental and Energy Study Institute, March 27, 2018, http://www.eesi.org/articles/view/u.s.-leads-in-greenhouse-gas-reductions-but-some-states-are-falling-behind.

[69] See, e.g., Center for Climate and Energy Solutions, "Top companies urge White House to stay in the Paris Agreement," Center for Climate and Energy Solutions Press Release, April 2017, https://www.c2es.org/newsroom/releases/major-companies-urge-white-house-stay-paris.

wrote a few years ago in *The Guardian*, "retrofitting the global economy for climate change would help to restore aggregate demand and growth."[70] Consistent with this, the High-Level Commission, which I co-chaired with Lord Stern,[71] found that "climate policies, if well designed and implemented, are consistent with growth, development, and poverty reduction. The transition to a low-carbon economy is potentially a powerful, attractive, and sustainable growth story, marked by higher resilience, more innovation, more livable cities, robust agriculture, and stronger ecosystems."[72]

51. However, instead of supporting existing clean energy technology that would benefit the economy and create jobs, Defendants are acting in ways to suppress and hinder clean energy, which also leads to job losses and harms the economy. For example, in January 2018, President Trump approved tariffs on imported solar cells that start at 30 percent. The tariffs are unlikely to benefit American solar manufacturing jobs, but, according to the Solar Energy Industries Association, are likely to result in the loss of 23,000 American jobs this year and the delay or cancelation of billions in solar investments. The tariffs are also expected to lead to a net reduction in solar installations by roughly 11 percent between 2018 and 2022, a 7.6-gigawatt reduction in solar PV capacity, which means approximately 1.2 million homes will not be powered by renewable solar energy. Such tariffs are both harmful for the environment and the economy.[73]

52. Not promptly undertaking actions to pursue clean-energy technology continues to expose Youth Plaintiffs and Affected Children to the risk of extreme costs and damages, not just from climate change itself, but from the required outlays on future remediation and adaptation efforts and a weaker, less efficient, and more expensive U.S. economy.

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[70] Stiglitz, J., "Climate Change and Poverty Have Not Gone Away," *The Guardian*, January 7, 2013, https://www.theguardian.com/business/2013/jan/07/climate-change-poverty-inequality

[71] Lord Stern succeeded me as Chief Economist of the World Bank and subsequently was a leading economic advisor to the UK Treasury, as Second Permanent Secretary and head of the Government Economic Service.

[72] High-Level Commission on Carbon Prices, "Report of the High-Level Commission on Carbon Prices," 2017, Washington, DC: World Bank, p. 1.

[73] Julia Pyper, "New Tariffs to Curb US Solar Installations by 11% Through 2022," *Greentech Media,* January 23, 2018, https://www.greentechmedia.com/articles/read/tariffs-to-curb-solar-installations-by-11-through-2022#gs.YNyvdYQ

B. POLLUTION IS A CLASSIC EXTERNALITY THAT CAN BE COMBATED WITH STANDARD ECONOMIC TOOLS THAT PROMOTE SOCIAL WELFARE

53. Currently, around 80 percent of the energy consumed in the U.S. comes from fossil fuels.[74] In contrast, renewable energy sources comprise 11 percent of total energy consumption. That percentage has only risen by 2 percent (9 to 11 percent) from 1949 to 2017.[75]

54. The burning of fossil fuels generates large amounts of pollution. Pollution is the archetypal negative externality. In economics, an externality arises when the cost or benefit of an activity of one party imposes a cost or benefit on another. In the pollution example, the polluter makes a good (its primary activity), but in the course of doing so generates pollution that imposes a cost or burden on another (e.g., a fisherman who fishes in the waters that become polluted will catch fewer fish). A positive externality example might be a technological development that benefits more than the inventor alone (e.g., the developer of the worldwide web who made it freely available).

55. The issue that arises with a negative externality is that the producer of the externality (e.g., the polluter) considers only their private costs when making production decisions and not the total costs of their activity (the costs borne by the polluter and the fisherman). Standard economic theory argues that private markets can be relied on to make efficient decisions, if, and only if, the (marginal private) costs confronting individuals equal the (marginal) social costs, and the (marginal private) benefits confronting them equal the (marginal) social benefits. When there is an externality, social and private costs and/or benefits are not aligned. A classic way to intervene in this situation is for government to tax the causes of negative externalities (thereby raising the effective private cost closer to

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[74] U.S. Energy Information Administration, Table 1.3 Primary Energy Consumption by Source, March 2018 Monthly Energy Review, https://www.eia.gov/totalenergy/data/browser/xls.php?tbl=T01.03&freq=m.

[75] U.S. Energy Information Administration, Table 1.3 Primary Energy Consumption by Source, March 2018 Monthly Energy Review, https://www.eia.gov/totalenergy/data/browser/xls.php?tbl=T01.03&freq=m.

the social cost and forcing the producer to bear the full cost of their actions).[76] Having a well-functioning price system—where price setters take into account all costs—is important for economic efficiency and overall social welfare.

56. At present, the U.S. lacks a comprehensive carbon-pricing regime that accounts for the negative externalities of burning fossil fuels such that private markets can be relied on to make efficient decisions. Thus, producers and sellers of fossil fuels consider only their private costs and benefits, and the costs that their activities are imposing on society through, among other factors, increased GHG emissions and long-term climate effects of the sort I discussed earlier are not considered or internalized as part of the price.

57. Beyond the lack of a comprehensive carbon-pricing regime, a faulty system that is full of hidden subsidies for fossil fuels, as noted above, hinders the transition towards a less carbon-intensive economy. These subsidies also accelerate and exacerbate the costs to Youth Plaintiffs from climate change.

58. These subsidies take many forms. For instance, upstream oil and gas exploration and production companies in the U.S. receive several tax breaks that go beyond those afforded to businesses generally, such as deducting intangible drilling costs as a current business expense (not capitalized over the life of the well), depletion allowances,[77] and offshore drilling tax royalty relief (which permits the claiming of foreign royalties as taxes (and makes them creditable against U.S. taxes) for taxpayers taxed in two countries). When companies make an investment, it is natural that they be allowed to depreciate the cost of the capital as a tax-deductible expense over the lifetime of the asset.

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[76] Sometimes, governments have to rely on "second best" interventions. Thus, government can subsidize alternatives (or positive-externality activities), which lowers the effective price of substitute products. Lowering the price of a substitute product can have the effect of increasing demand for the substitute (e.g., clean energy) and reducing the demand for the original product (e.g., fossil fuel-based energy). But leaving the negative externality-generating activity without a "charge" for its external effects leaves a distortion in place.

[77] I have studied the economics of depletion allowances, together with Sir Partha Dasgupta, in my academic work. See, J.E. Stiglitz, "Monopoly and the Rate of Extraction of Exhaustible Resources," *The American Economic Review* 66(4) (September 1976): 655-661 and P. Dasgupta and J.E. Stiglitz, "Uncertainty and the Rate of Extraction Under Alternative Arrangements," *Institute Mathematical Studies in the Social Sciences*, tech. rep. no. 179 (September 1975).

But with depletion allowances, an oil company can deduct 15 percent of the revenue as a "depletion allowance," regardless of the amount of investment it made to find the oil.[78] The company receives the depletion allowance—as if it invested money—even if it makes no investment. The value of this provision itself is enormous; some estimates say it could save the U.S. Treasury over $11 billion in 10 years if it were eliminated.[79] (Money not received by Treasury is, in effect, money given to the fossil fuel industry.) Coal companies can receive similar corporate tax reductions, and are able to purchase or lease land from Defendants at below market rates.[80] These tax breaks artificially reduce the private cost of fossil fuels to producers and consumers (but not the social cost), which makes renewable sources of energy appear less competitive to consumers.[81] In the U.S., these tax breaks for fossil fuel companies have resulted in an economy heavily dependent on fossil fuels and infrastructure designed around fossil fuels.

59. Similarly, at various times, oil, gas, and coal leases have been conducted in ways in which fossil fuel companies are able to obtain leases at prices far below what the competitive equilibrium price would be, depriving taxpayers of money they need for a variety of public purposes, while distorting the market to make participation in oil, gas, and coal more economically attractive.[82] The efficient auctions that have been used in

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[78] This provision dates to 1913. See, e.g., Rebecca Leber, "Happy 100th Birthday, Big Oil Tax Breaks," *Think Progress*, March 1, 2013, https://thinkprogress.org/happy-100th-birthday-big-oil-tax-breaks-3c9731c4bc85/. See also, Seth Hanlon, "Big Oil's Misbegotten Tax Gusher," *Center for American Progress*, May 5, 2011, https://www.americanprogress.org/issues/economy/news/2011/05/05/9663/big-oils-misbegotten-tax-gusher/.

[79] See, Seth Hanlon, "Big Oil's Misbegotten Tax Gusher," *Center for American Progress*, May 5, 2011, https://www.americanprogress.org/issues/economy/news/2011/05/05/9663/big-oils-misbegotten-tax-gusher/.

[80] Doukas, Alex, "G20 subsidies to oil, gas and coal production: United States", Overseas Development Institute, 2015, https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9979.pdf.

[81] Bridle, Richard, Kitson, Lucy, "The Impact of Fossil-Fuel Subsidies on Renewable Electricity Generation", International Institute for Sustainable Development, December 2014, http://www.iisd.org/sites/default/files/publications/impact-fossil-fuel-subsidies-renewable-electricity-generation.pdf.

[82] This was the case, for instance, in the early 1980s, when large numbers of tracts were simultaneously put up for auctions, so many that the average tract had less than two bidders. I discussed some of the

Continued on next page

other areas (e.g., for the auctioning of the electro-magnetic spectrum) were typically never used. A 2016 report from the President's Council of Economic Advisors regarding coal leases recognized several of these points explicitly, noting, for example, that the coal leasing program "has been widely criticized in recent years by economic and environmental experts for providing a poor return to the taxpayer and for not adequately addressing the environmental costs of coal extraction, processing, and combustion."[83] The report also found that previous and then-current policies of Defendants had misaligned incentives: "the program has been structured in a way that misaligns incentives going back decades, resulting in a distorted coal market with an artificially low price for most Federal coal and unnecessarily low government revenue from the leasing program."[84] The report suggests that to fully reflect the social costs of coal extraction—i.e., price the externality completely—the costs are so high that the resulting royalty rate may be "well-over 100 percent."[85]

Continued from previous page

research in this instance in my Nobel lecture. See, J.E. Stiglitz, "Information and the Change in the Paradigm in Economics," Prize Lecture, December 8, 2001, pp. 489-490, https://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/2001/stiglitz-lecture.pdf.

See also, J.J. Leitzinger and J.E. Stiglitz, "Information Externalities in Oil and Gas Leasing," *Contemporary Policy Issues* 5 (March 1984): 44-57 and J.E. Stiglitz, "What is the Role of the State?" Chapter 2 in M. Humphreys, J.D. Sachs, and J.E. Stiglitz (eds.) "Escaping the Resource Curse," 2007, Columbia University Press, pp. 23-52 at p. 31: "When competition for the resources is limited—and especially when it is known that it is limited—then the prices that prevail will be lower. There are three ways of limiting competition. The first is suddenly to put up for lease a large number of tracts—increase the supply so that the bidding on each tract is limited. This is what President Reagan did in the early 1980s. It was like a fire sale—as if the government had to get rid of its holdings immediately. But in fact, there was no reason for it; it was not as if the oil was going to disappear, or as if the United States needed to raise cash quickly. On a very large fraction of tracts, there was only one bidder (and, of course, the oil companies knew this). In a study I conducted with Jeff Leitzinger (1984) we quantified the impact on the price the government received. The government got a fraction of what it would have earned had the tracts been put up in a more orderly process, and the extra profits went into the coffers of the oil companies."

83 "The Economics of Coal Leasing on Federal Lands: Ensuring a Fair Return to Taxpayers," Executive Office of the President of the United States, June 2016, at p. 2, https://obamawhitehouse.archives.gov/sites/default/files/page/files/20160622_cea_coal_leasing.pdf.

84 *Id.*

85 *Id.* at p. 29.

60. An important source of protection against global warming is carbon-sequestration—holding carbon in trees, plants, wetlands, or soils. Carbon molecules that are thus held are carbon molecules that are not in the atmosphere.[86] There are large amounts of public land holding millions of acres of trees, but the government has an industry-driven policy framework in which (a) the timber industry, which acquires the right to cut down the timber, does not pay for the carbon costs of their activities; (b) the timber industry is typically subsidized through roads constructed by the Department of Agriculture, which manages these public forests; (c) the timber industry, like the fossil fuel industry, receives favorable tax benefits; and (d) the timber industry acquires these assets at prices that are below prices that would prevail in a competitive market that accounted for all private and public costs of logging.[87]

61. The provision of these tax benefits and the sale and/or lease of these public assets at below competitive market prices by Defendants harms the U.S. today, and these Youth Plaintiffs and Affected Children, in multiple ways. The harm to the U.S. arises because improper pricing that ignores the externalities of logging leads to inefficient uses of forests, logs, and wood products that would not materialize if the price of logs reflected the carbon costs of cutting down the trees and releasing CO_2 into the atmosphere. These actions by Defendants support the destruction of forests, which are needed to sequester CO_2 (not to mention all the critical ecosystem benefits forests provide). The poorly functioning price mechanism deprives our society of governmental revenues that could be used for multiple purposes, including investment in emission reductions and investments in R&D that would facilitate the transition towards a green economy; and forces taxes to be imposed elsewhere, with distortionary costs—so that total costs to society are well in excess of the losses of tax revenues. The resulting weaker economy

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86 For a more thorough articulation of this framework, see J.E. Stiglitz, "Sharing the Burden of Saving the Planet: Global Social Justice for Sustainable Development: Lessons from the Theory of Public Finance," Columbia University Academic Commons, https://doi.org/10.7916/D8KD24MX and Mary Kaldor and Joseph E. Stiglitz, eds., *The Quest for Security: Protection without Protectionism and the Challenge of Global Governance*, New York: Columbia University Press, pp. 161-190.

87 See, e.g., "Congressional Subsidies for Private Logging," Taxpayers for Common Sense, December 13, 2001, http://www.taxpayer.net/library/article/congressional-subsidies-for-private-logging.

means that Youth Plaintiffs are inheriting an economy that is not only dirtier than it otherwise would have been, but also weaker.

62. There are also indirect explicit subsidies that contribute to the continued reliance on fossil fuels, such as government investments and policies that promote emission producing methods of transportation or manufacturing.

63. Another implicit subsidy granted by governments is to not charge the fossil fuel industry for the negative externalities they create, such as carbon emissions. As discussed above, carbon emissions, and pollution in general, are negative externalities that can affect society and the economy, yet the vast majority of negative-externality carbon emissions across the globe are not priced.[88] Pricing CO_2 emissions and emissions of other GHGs would greatly enhance revenues available to government to address a variety of societal needs, as I discussed in Section IV above. A basic principle of taxation is that it is better to tax bad things like pollution than good things like savings and work. Again, the resulting weaker economy means that Youth Plaintiffs are inheriting an economy that is not only dirtier than it otherwise would have been, but also weaker. In this instance, not only are Defendants not raising revenue in an efficient way (subsidizing rather than taxing carbon emissions), Youth Plaintiffs are burdened with the socioeconomic costs that arise with pollution, such as additional healthcare costs.

64. Defendants have recognized for at least 40 years that these direct and indirect subsidies to fossil fuel producers hinder the adoption of renewable energy and improvements in

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[88] See, e.g., High-Level Commission on Carbon Prices, "Report of the High-Level Commission on Carbon Prices," 2017, Washington, DC: World Bank, at p. 35: "The carbon prices observed span from less than US$1/tCO2e to US$126/tCO2e, 85 percent of global emissions are not priced today…"

Because all emissions generate externalities, for an efficient economy, all emissions should be taxed. In a few instances, the adverse effects of not taxing the emissions can be mitigated by the imposition of regulations.

renewable energy technologies. For example, a 1978 memo to President Carter regarding solar power found that:[89]

> Widespread use of solar energy is also hindered by Federal and state policies and market imperfections that effectively subsidize competing energy sources. These policies include Federal price controls on oil and gas, a wide variety of direct and indirect subsidies, and utility rate structures that are based on average, rather than marginal costs. Also, the market system fails to reflect the full social benefits and costs of competing energy sources, such as the costs of air and water pollution.

65. If Defendants stopped providing subsidies and/or implemented carbon pricing policies that allow the U.S. government to further fund research and development of green technologies to decarbonize the economy, such measures would have a large positive impact in the long term. These positive effects are not limited to mitigating the environmental effects; there are monetary gains, too. Some estimates of the financial benefit to the U.S. economy of accelerating technological developments for lowering carbon emissions suggest that they would amount to $1 trillion by 2050.[90]

66. This monetary estimate does not take into account possible spillover effects from advancing technology that could provide further value to the economy (e.g., in the same way that the space race or developments in the world wars brought us many advancements in basic science that made their way into consumer and industrial products). Even without technological change, the net financial costs to the economy may be negative, taking into account the financial benefits of eliminating carbon subsidies and replacing them with carbon taxes and the consequent development of a more efficient low-carbon energy system.

67. A short-term measure Defendants can readily implement is to cease approvals for any new fossil fuel infrastructure, pending completion of a national climate recovery plan. Any new coal projects or coal extraction harms Youth Plaintiffs. For example, it

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[89] Attachment to Memorandum from Jim Schlesinger to The President, "Domestic Policy Review of Solar Energy: A Response Memorandum to The President of the United States," December 5, 1978, at p. iv.

[90] Richard G. Richels, Geoffrey J. Blanford, "The value of technological advance in decarbonizing the U.S. economy," *Energy Economics* 30(6) (2008): 2930-2946, ISSN 0140-988.3.

increases GHG emissions locking in higher concentrations of GHGs in the atmosphere as Youth Plaintiffs grow up and live their lives, with all the attendant costs and impacts that I have described thus far. Enabling investments in long-lasting "fossil" infrastructure (like coal-burning power plants and oil and natural gas pipelines) means that for decades going forward, there will continue to be incentives to engage in costly carbon emissions. Once the plants are built, the owners have an incentive to continue using it to recover their investment (and in so doing, generate GHG emissions). Furthermore, should a fossil-fuel plant be shut down before the natural end of its economic life, there will be allegations of lost economic value (the owners' private loss on their investment). Such allegations will become a political argument against taking further actions curbing emissions. (These arguments will almost surely be put forward even though the public benefits of shutting down the coal fired plants may be enormous—as I have noted—and even though a standard argument in economics is that bygones-are-bygones. Mistaken investments in the past should not continue to justify distorted power generation. Elsewhere, however, the "politics" of stranded assets has played an important role—that is to say; private owners of large, sunk investments have (successfully) argued for preferential treatment for them to recoup their private investments, despite the attendant social costs.)

68. I should also respond to an expected argument from Defendants that, even if the U.S. were to lower its GHG emissions, other countries would increase their production of goods that create GHGs. This might be referred to as a "substitution" argument. There are two rejoinders to this:

a. First, I turn to standard economic theory. That is, that in any given equilibrium the lowest-cost providers are providing any given resources. Thus, if the U.S. is providing GHG-dependent products today, it is because the marginal cost of the U.S. providing such products is below the next-cheapest alternative. If the U.S. were to cease producing, say, 100 "units" of GHGs, the next-cheapest alternative would increase its production by less than 100 "units" (because if it made economic sense for the next-cheapest alternative to produce more than 100 "units" they would already be doing so). As such, any substitution will be less than perfect and reductions in

U.S. emissions will be offset less than one-to-one by alternative supplies (i.e., there will be a net reduction).

b. Second, specific to GHG emissions, recent technical studies have shown that U.S. emissions will not be perfectly offset.[91] This is consistent with the general theory I mentioned above. While climate change is a global problem, the U.S. is a significant contributor to GHG emissions, and so actions by the U.S., both directly, and by the leadership which such actions provide, has a significant impact on these global outcomes. Indeed, the U.S. stands out as the sole country announcing that it is not committed to the reduction of carbon emissions, having announced that it will leave the Paris Agreement. Despite the U.S.'s actions, other countries remain committed. Thus, if the U.S. were to recommit itself to climate action, there is no significant risk of other countries polluting more, so as to offset the benefits of U.S. reductions in carbon emissions.

69. The government has recognized since the 1980s that the U.S. will need to take a leadership role in climate change. For example, a government memorandum from 1989 discusses the desire for the U.S. to have a leadership role in addressing climate change. The memorandum also makes clear that when it comes to addressing climate change the U.S. "simply cannot wait -- the costs of inaction will be too high."[92]

C. Defendants' Use of Discounting in Decision-Making Underestimates the Costs of Climate Change on Youth Plaintiffs and Future Generations and the Benefits of Mitigation, with Deleterious Consequences

70. In running the government, Defendants must repeatedly make decisions about projects and policies. They must evaluate alternative choices with which they are confronted. In this section, I explain that the way Defendants do this systematically undermines the

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[91] See, e.g., P. Erickson and M. Lazarus, "Would constraining US fossil fuel production affect global CO2 emissions? A case study of US leasing policy," *Climatic Change*, 2018, https://doi.org/10.1007/s10584-018-2152-z.

[92] Memorandum from Frederick M. Bernthal to Richard T. McCormack, Department of State, February 9, 1989, attachment "Environment, Health and Natural Resources Issues," and responses to "Question #1."

interests of Youth Plaintiffs in a way which cannot be justified. Indeed, economic science provides sound alternative methodologies for the evaluation of policies and projects which systemically lead to better outcomes for society in general, and would not systematically discriminate against Youth Plaintiffs in the way that existing policies do.

71. While there are a number of longstanding and well-established perspectives in economics which recognize that delaying the kinds of precautionary actions suggested above is deleterious to societal welfare, government practices and procedures underlying important decision-making systematically undervalue the costs to be borne by future generations (including Youth Plaintiffs and Affected Children).

72. The issue devolves around how governments should value benefits and costs that arise at some future date relative to those that occur today. Typically, less value is given to future effects than to current effects. The question is, how much less. Since the most catastrophic effects of climate change may not be felt for years (see paragraph 27 and footnote 19, above), saying that what happens in the future does not matter much biases public decision making against taking actions to protect Youth Plaintiffs.

73. The standard methodology for making such assessments is called cost-benefit analysis. In a cost-benefit analysis, using a discount rate is commonplace; however, that discount rate must be appropriate. As I have noted, issues around discounting are especially important in the context of climate change because the full benefits may not accrue for many years after society incurs costs to limit the emissions of GHGs.[93]

74. Formal intertemporal analysis on which so much of modern economics is based originated with the path breaking work of Frank Ramsey, who argued that there was no ethically defensible justification for discounting the well-being (utility) of future

[93] There is also a problem with how discounting is often applied when we consider future costs compared to future benefits. Standard economic theory says that risky future benefits (e.g., uncertainty regarding an investment's return) are discounted to account for that risk. That is, risky benefits are worth less than riskless benefits. When we consider costs, however, analysts often *reduce* risky costs: uncertainty regarding future costs should decrease the value of a project (i.e., increase its costs), not increase the value of a project.

generations.[94] In the almost one century since his work, no one has developed a persuasive argument to the contrary.[95]

75. There is an argument that future consumption should be discounted, since future incomes are assumed to be higher, and standard arguments of diminishing marginal utility imply that if that is the case, the value of consumption will be lower. But the high discount rates used by Defendants can only be justified by the assumption of high future increases in standards of living. Since 2008, there is overwhelming evidence that the pace of productivity has declined markedly, implying that we cannot count on past rates of increases prevailing in the future. There is one school of thought (studied and advocated by Prof. Robert Gordon at Northwestern) that argues even the current pace of

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94 Clearly, if one thought that the world would end, say in 50 years, as a consequence of a nuclear war, unrelated to climate change, one would not need to take into account events beyond the 50-year extension. We rule out such possibilities, or assume that they are of sufficiently low probability as not to affect our analysis.

For mathematical tractability, many analyses assume a small, positive pure intergenerational discount rate. While ethically indefensible for our purposes, the results are not much different from those obtained with a zero discount rate.

95 In the middle of the twentieth century, two teams of researchers, each with a prominent Nobel Prize winner, formulated "guides" to cost benefit analysis. See Dasgupta, Sen, and Marglin, prepared for UNIDO (the United Nations Industrial Development Organization) (P. Dasgupta, S.A. Marglin, A. Sen, *Guidelines for project evaluation*, United Nations Industrial Development Organization, Vienna (1972) (United Nations publication sales no.: E.72.II.B.11)) and Little and Mirrlees, prepared for OECD Development Center (I.M.D. Little and J.A. Mirrlees, *Manual of Industrial Project Analysis in Developing Countries vols. 1 and 2*, OECD, Paris (1968, 1969). Amartya Sen received the Nobel prize in 1998, Partha Dasgupta was knighted in 2002, Ian Little was the Deputy Director of the Economic Section at the U.K. Treasury and a distinguished Oxford development economist, and Sir James Mirrlees received the Nobel Prize in 1996.

In the 1970s, discounting became important as the country thought through how to respond to the oil price shocks: what were the requisite changes to its energy system? Though this was done in an era before the costs of carbon emissions were widely understood, the principles are still relevant. See J.E. Stiglitz, "The Rate of Discount for Cost-Benefit Analysis and the Theory of the Second Best," *Discounting for Time and Risk in Energy Policy*, R. Lind (ed.), Baltimore: The Johns Hopkins University Press, 1982, pp. 151-204.

There have been various guidelines published on this topic for internal government use, see, for example: OMB Circular No. A-94, "Discount Rates to be Used in Evaluating Time-Distributed Costs and Benefits" (Mar. 27, 1972) and OMB Circular No. A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs", Oct. 1992.

productivity—far lower even than in the recent past—may decline still more.[96] Whether one agrees with Gordon's assessment or not, this recent discussion has brought out four key points:

a. There is considerable uncertainty about the pace of increase in living standards.

b. The pace of increase in living standards is endogenous—it depends on what actions we take.

c. If there is significant climate change, and if we continue on our current path, there is a significant risk of a decrease in standards of living.

d. The marginal value of consumption is likely to be high in those states of nature where climate change is greater, and where the adverse effects of climate change are large. That is to say, the value of additional consumption—the ability to build or consume more—and therefore its price will be higher when the effects of climate change are greater. Thus, in those places where the effects of climate change are most pronounced—where damage is the greatest and remediation need and costs are the highest—the *social cost* of such remediation will also be at its highest, exacerbating the damages to Youth Plaintiffs (both because when damages are high, the cost of remediation is also high, and because levels of consumption—what is left over after paying for remediation costs, and taking into account the damage done by climate change—are low).

76. It would be foolhardy—and wrong—for public policy to proceed as if there were no risk, either of a decrease in living standards, and especially of a lowering of those standards as a result of a failure to appropriately curtail emissions.

77. Standard economics over the past half century has emphasized the importance of risk aversion, and that risk affects our actions. Common usage of discounting in public finance fails to take account of risk appropriately. When individuals are risk averse, they

[96] See, R.J. Gordon, *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War*, Princeton University Press, 2016. See also, R.J. Gordon, "Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds," *NBER Working Paper*, No. 18315, August 2012, http://www.nber.org/papers/w18315.pdf.

are willing to buy insurance against a risk—to pay a considerable risk premium. This is also true for the business sector and society in general. This is especially important when we assess the appropriate response to the threat of climate change. The planet Earth cannot buy insurance from another planet against the risk of climate change here, but we can take precautionary actions. At the very least, this implies that the discount rate used for assessing climate change actions should be markedly different from that used for conventional short-term projects. As Chairman of the Council of Economic Advisers, I headed a review committee for the Office of Management and Budget (OMB) reviewing the guidelines for discounting, and that was the conclusion we reached in the late 1990s—that one must account for changes in relative price over time, and when our environment becomes more valuable in the future (i.e., as the value of preserving it becomes higher) that must be reflected in the economic analysis.[97] This was consistent with the position taken in the 2nd assessment of the IPCC, and in a paper I co-authored with the late Nobel laureate Kenneth Arrow and others.[98]

78. More than half a century ago, President Johnson sent a message to Congress that we faced two paths: the cheaper option, in the short-term, of carrying down the path of pollution, or the more expensive option (at the time), of restoring the country and its natural heritage to the people.[99]

> We are able to see the magnitude of the choice before us, and its consequences for every child born on our continent from this day forward. Economists estimate that this generation has already suffered losses from pollution that run into billions of dollars each year. But the ultimate cost of

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[97] Our report was issued in 1996: "Economic Analysis of Federal Regulations Under Executive Order 12866," The White House, January 11, 1996, https://obamawhitehouse.archives.gov/omb/inforeg_riaguide/.

[98] K. Arrow, W.R. Cline, K-G. Maler, M. Munasinghe, J. E. Stiglitz, and R. Squitieri, "Intertemporal Equity and Discounting," in *Global Climate Change: Economic and Policy Issues,* M. Munasinghe (ed.), World Bank Environment Paper 12, Washington, D.C. 1995, pp. 1-32. Reprinted in an abbreviated format as "Intertemporal Equity, Discounting, and Economic Efficiency," *Climate Change 1995: Economic and Social Dimensions of Climate Change,* J. Bruce, H. Lee, and E. Haites (eds.), Cambridge: Cambridge University Press, 1996, pp. 125-144.

[99] "Preserving Our Natural Heritage," Message from the President of the United States, transmitting "Programs for Controlling Pollution and Preserving our Natural and Historical Heritage," February 23, 1966.

> pollution is incalculable. We see that we can corrupt and destroy our lands, our rivers, our forests, and the atmosphere itself all in the name of progress and necessity. Such a course leads to a barren America, bereft of its beauty, and shorn of its sustenance. We see that there is another course more expensive today, more demanding. Down this course lies a natural America restored to her people. The promise is clear rivers, tall forests, and clean air – a sane environment for man.

79. For the last 50 years, Defendants have shirked from the "more demanding" course of restoring "America … to her people." Defendants' policies that discount the future of Youth Plaintiffs and Affected Children at inappropriately high rates continue to steer America on the path of incalculable losses and away from that more demanding and sane course. The costs of fixing the damage today are much higher than they would have been in 1966 when President Johnson sent his message; but, the costs today are much lower than what they will be after another 50 years of fossil fuel pollution and inaction.

VI. CONCLUSION

80. The choice between incurring manageable costs now and the incalculable, perhaps even irreparable, burden Youth Plaintiffs and Affected Children will face if Defendants fail to rapidly transition to a non-fossil fuel economy is clear. While the full costs of the climate damages that would result from maintaining a fossil fuel-based economy may be incalculable, there is already ample evidence concerning the lower bound of such costs, and with these minimum estimates, it is already clear that the cost of transitioning to a low/no carbon economy are far less than the benefits of such a transition. No rational calculus could come to an alternative conclusion. Defendants must act with all deliberate speed and immediately cease the subsidization of fossil fuels and any new fossil fuel projects, and implement policies to rapidly transition the U.S. economy away from fossil fuels.

81. This urgent action is not only feasible, the relief requested will benefit the economy. More importantly, this action is necessary if Defendants are to prevent the extreme cost and damages Youth Plaintiffs and Affected Children are facing and will face to an even greater extent if Defendants continue on a path that does not account for what is scientifically necessary to protect the climate system they depend on for their future well-being and their personal and economic security.

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